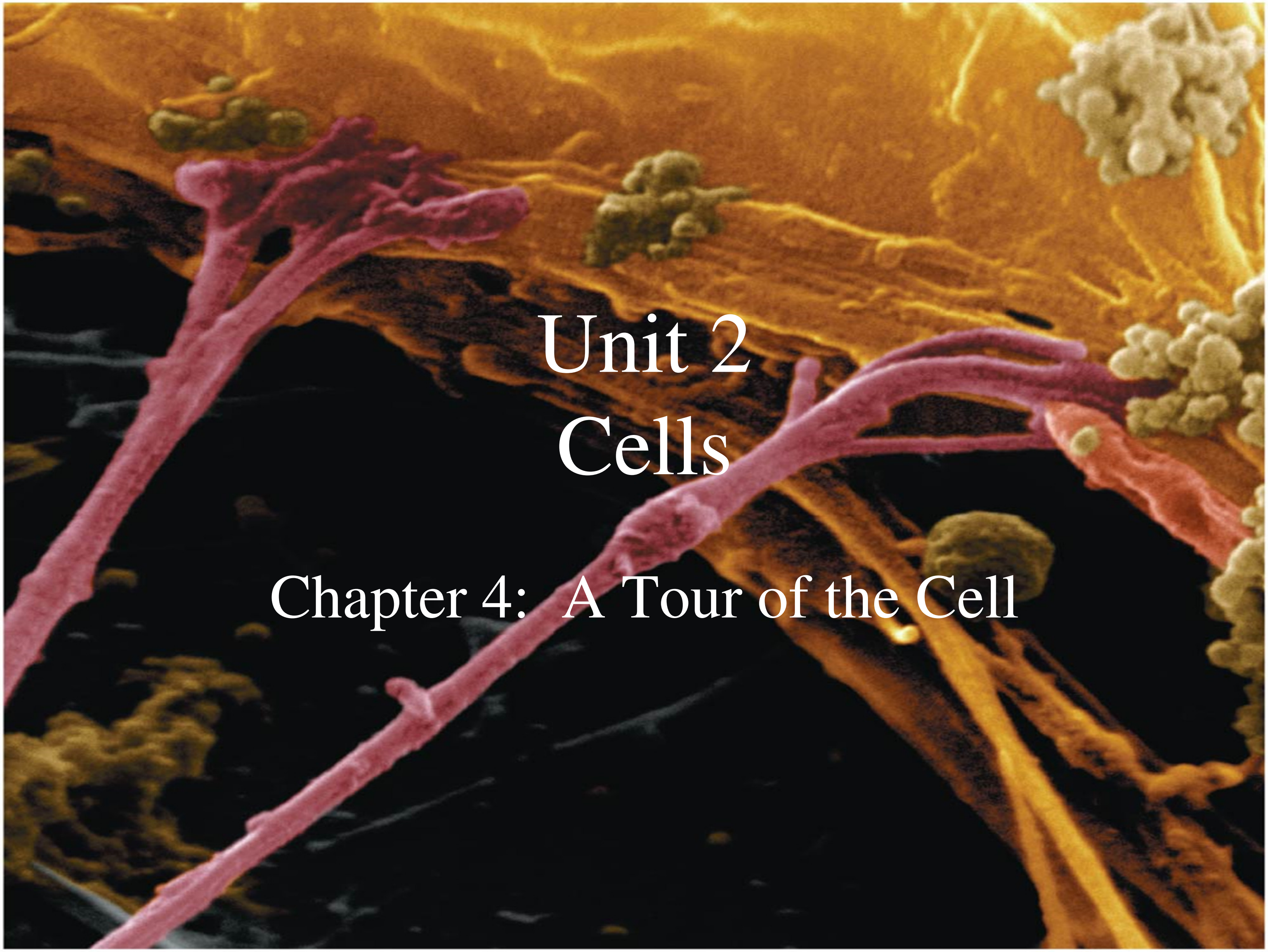


Unit 2
Cells

Chapter 4: A Tour of the Cell

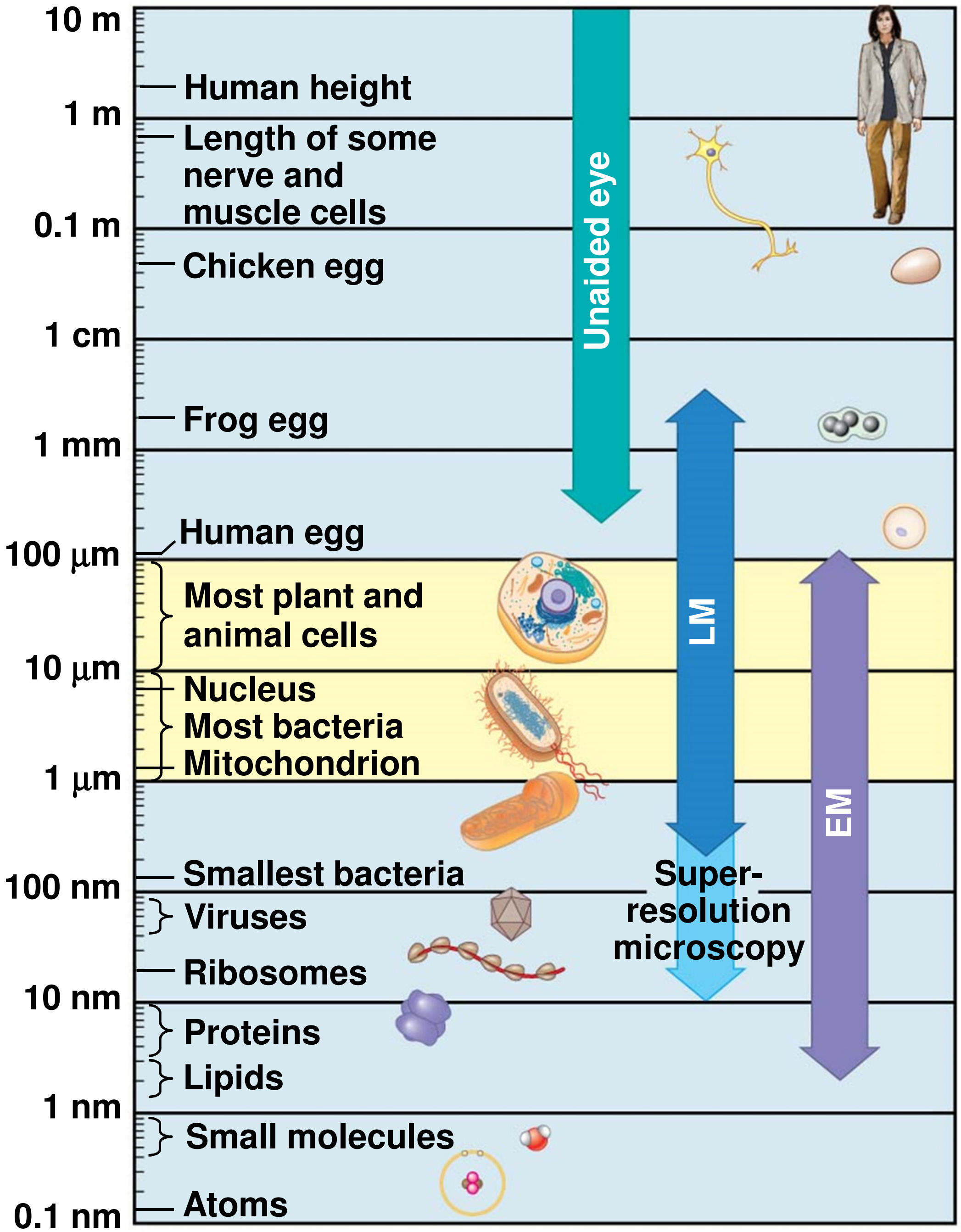
Overview: The Fundamental Units of Life

- All organisms are made of cells
  - The cell is the basic unit of structure and function of all living things
- Though cells can differ substantially from one another, they share common features

Concept 4.1: Biologists use microscopes and the tools of biochemistry to study cells

- Three important parameters of microscopy
  - Magnification, the ratio of an object's image size to its real size
  - Resolution, the measure of the clarity of the image, or the minimum distance between two distinguishable points
  - Contrast, difference in brightness between light and dark areas of an image

Figure 4.2



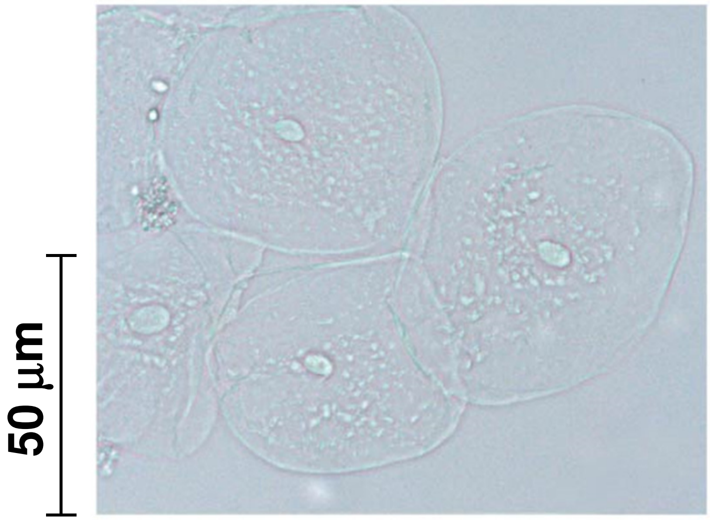
10 m
Human height
1 m
Length of some nerve and muscle cells
0.1 m
Chicken egg
1 cm
Frog egg
1 mm
Human egg
100 µm
Most plant and animal cells
10 µm
Nucleus
Most bacteria
Mitochondrion
1 µm
Smallest bacteria
100 nm
Viruses
Ribosomes
10 nm
Proteins
Lipids
1 nm
Small molecules
Atoms
0.1 nm
Unaided eye
LM
EM
Super-resolution microscopy

- In a **light microscope (LM)**, visible light is passed through a specimen and then through glass lenses
  - Lenses refract (bend) the light, so that the image is magnified
- LMs can magnify effectively to about 1,000 times the size of the actual specimen
- Various techniques enhance contrast and enable cell components to be stained or labeled
- Most subcellular structures, including **organelles** (membrane-enclosed compartments), are too small to be resolved by light microscopy

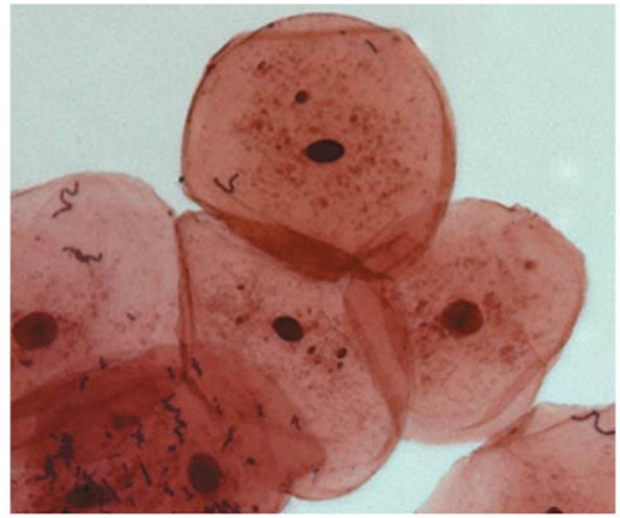
- Two basic types of **electron microscopes (EMs)** are used to study subcellular structures
- **Scanning electron microscopes (SEMs)** focus a beam of electrons onto the surface of a specimen, providing images that look three-dimensional
- **Transmission electron microscopes (TEMs)** focus a beam of electrons through a specimen
  - TEM is used mainly to study the internal structure of cells
- Disadvantage of EMs:
  - Methods used to prepare specimens kill the cells

Figure 4.3a

Light Microscopy (LM)

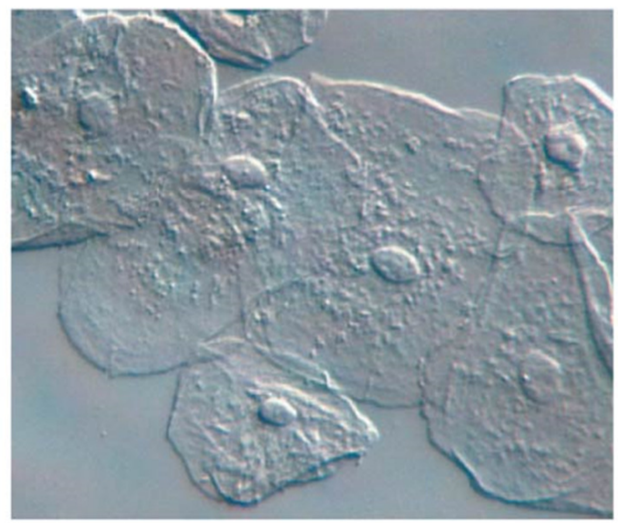


Brightfield (unstained specimen)



Brightfield (stained specimen)

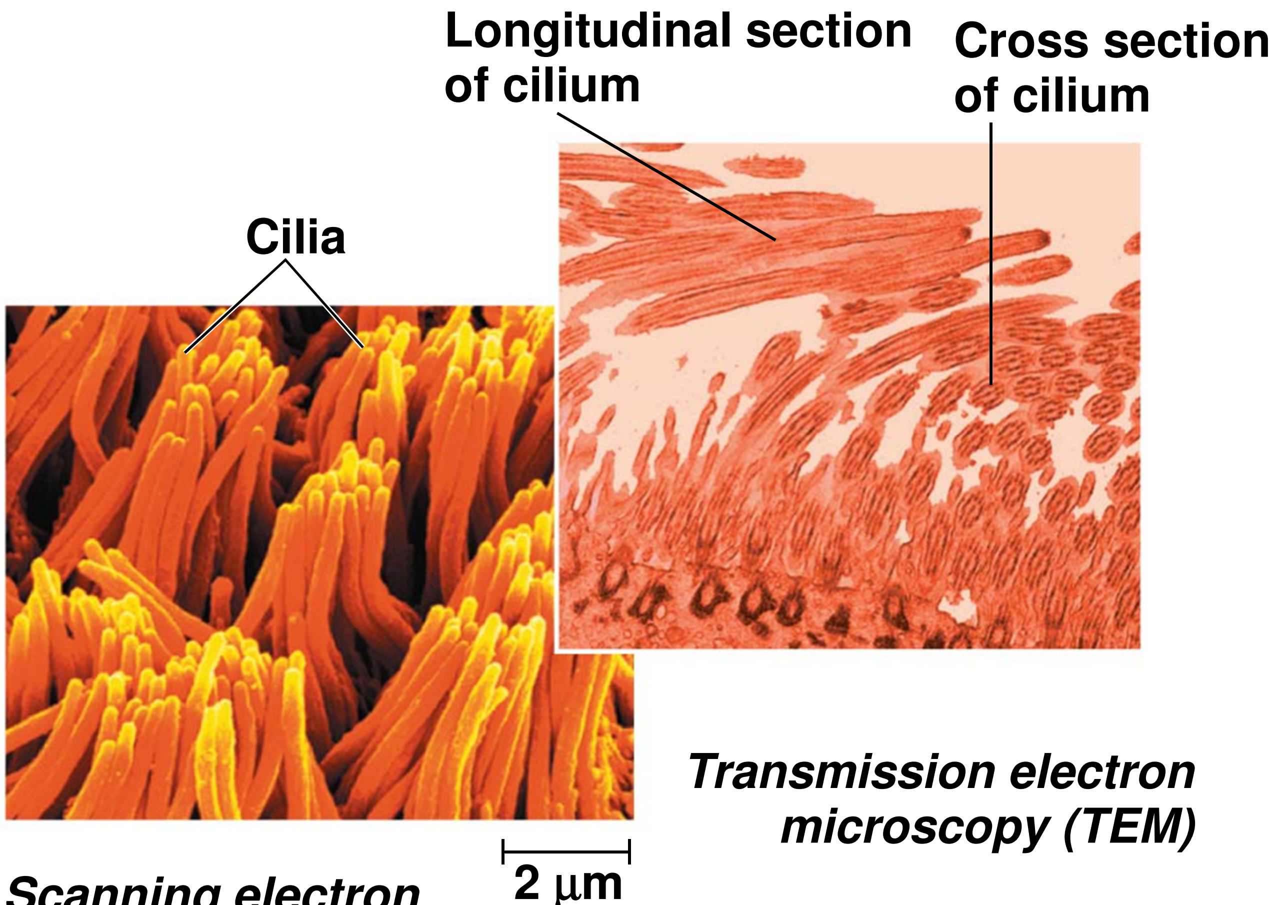
Phase-contrast



Differential-interference contrast (Nomarski)

Figure 4.3c

Electron Microscopy (EM)



Scanning electron microscopy (SEM)

Transmission electron microscopy (TEM)

- **Cell fractionation** breaks up cells and separates the components, using centrifugation
    - Cell components separate based on their relative size
- Cell fractionation enables scientists to determine the functions of organelles
- Biochemistry and cytology help correlate cell function with structure

Concept 4.2: Eukaryotic cells have internal membranes that compartmentalize their functions

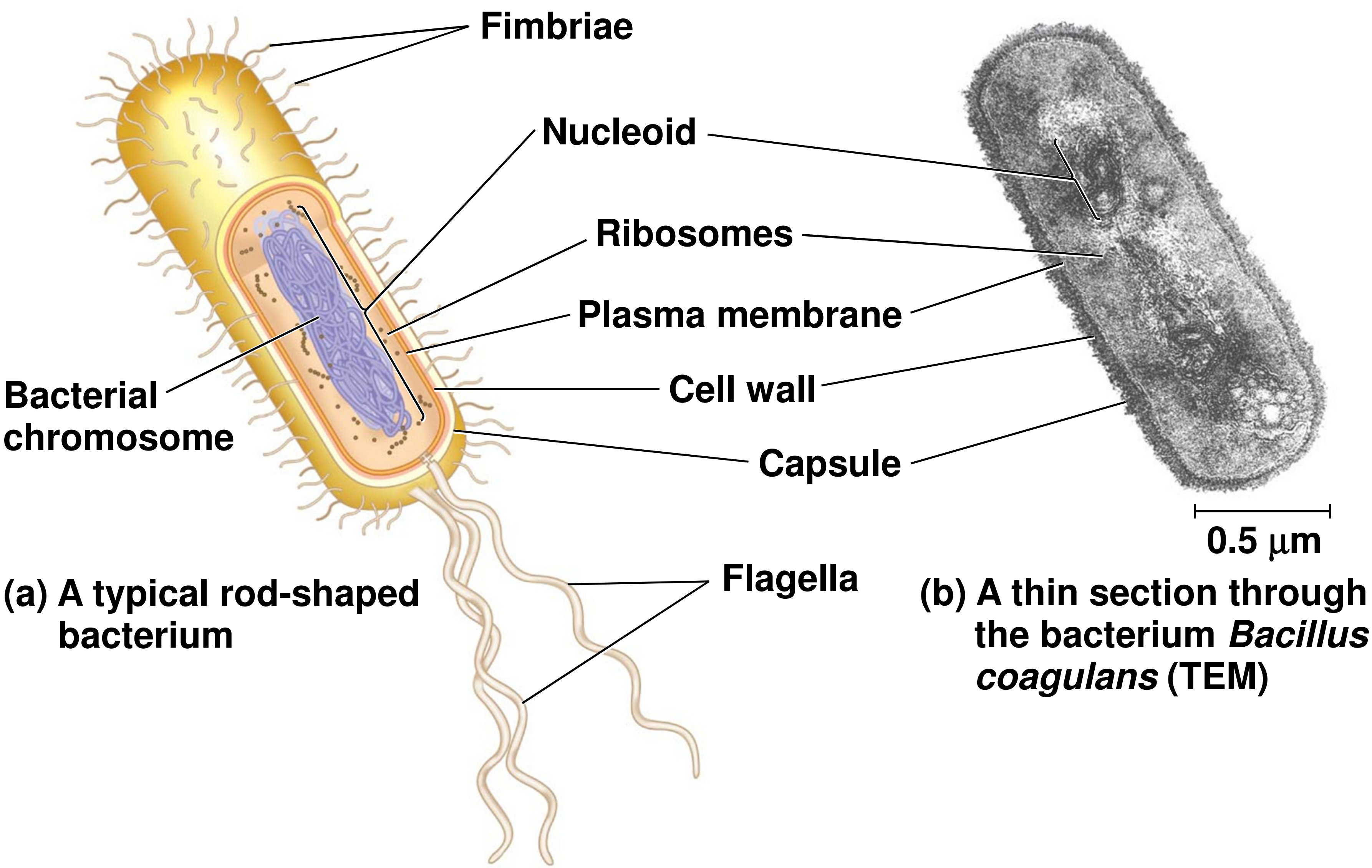
- The basic structural and functional unit of every organism is one of two types of cells: prokaryotic or eukaryotic
  - Organisms of the domains Bacteria and Archaea consist of prokaryotic cells
  - Protists, fungi, animals, and plants all consist of eukaryotic cells

Comparing Prokaryotic and Eukaryotic Cells

- Basic features of all cells:
  - Plasma membrane
  - Semifluid substance called **cytosol**
  - Chromosomes (carry genes)
  - Ribosomes (make proteins)
- Differences include:
  - Location of DNA
  - Size of cells
  - Internal organization

- **Prokaryotic cells** are characterized by having
  - No nucleus
  - DNA in an unbound region called the **nucleoid**
  - No membrane-bound organelles
  - **Cytoplasm** bound by the plasma membrane

Figure 4.4

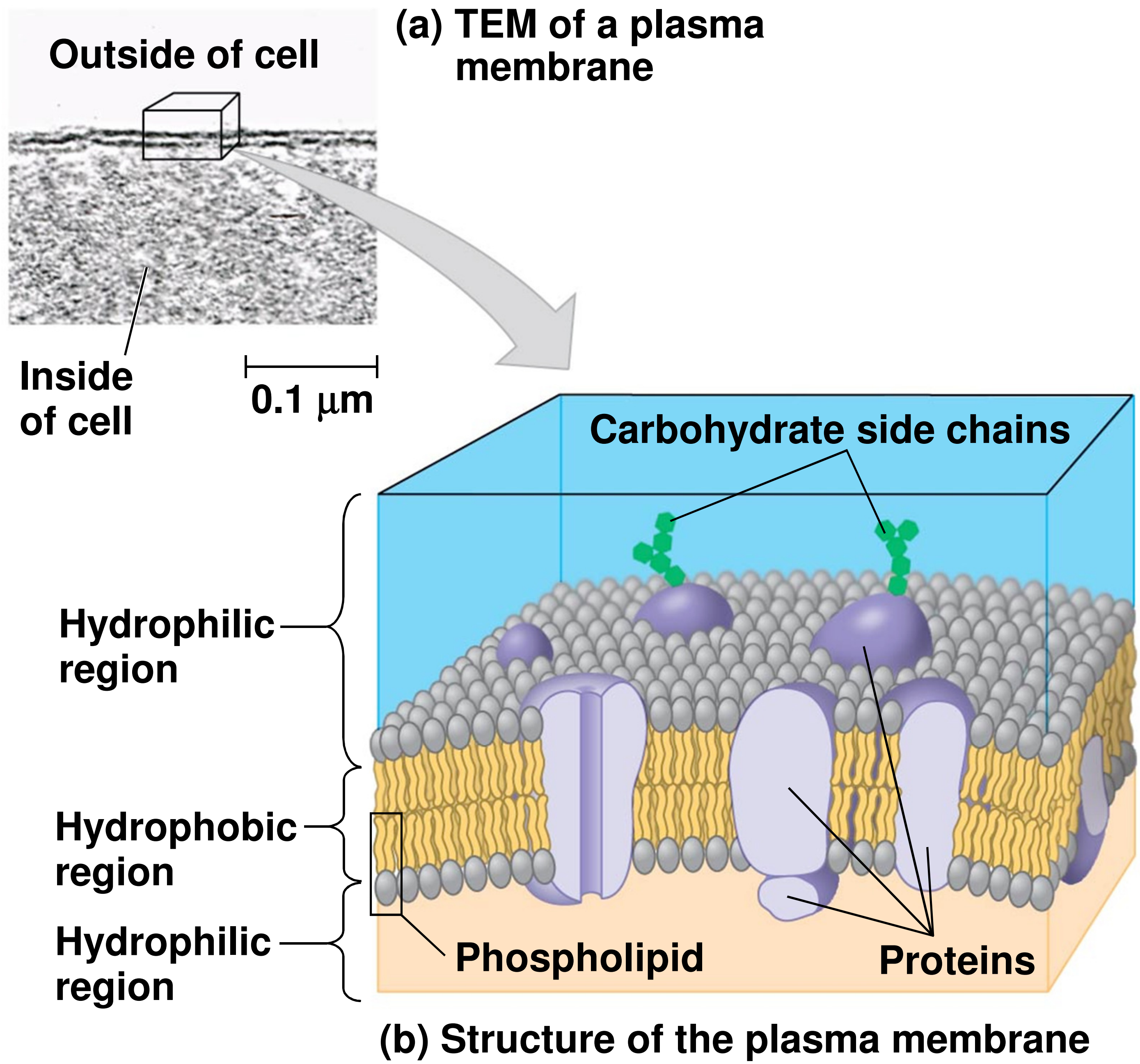


(a) A typical rod-shaped bacterium

(b) A thin section through the bacterium *Bacillus coagulans* (TEM)

- **Eukaryotic cells** are characterized by having
  - DNA in a nucleus that is bounded by a membranous nuclear envelope
  - Membrane-bound organelles
  - Cytoplasm in the region between the plasma membrane and nucleus
- Eukaryotic cells are generally much larger than prokaryotic cells

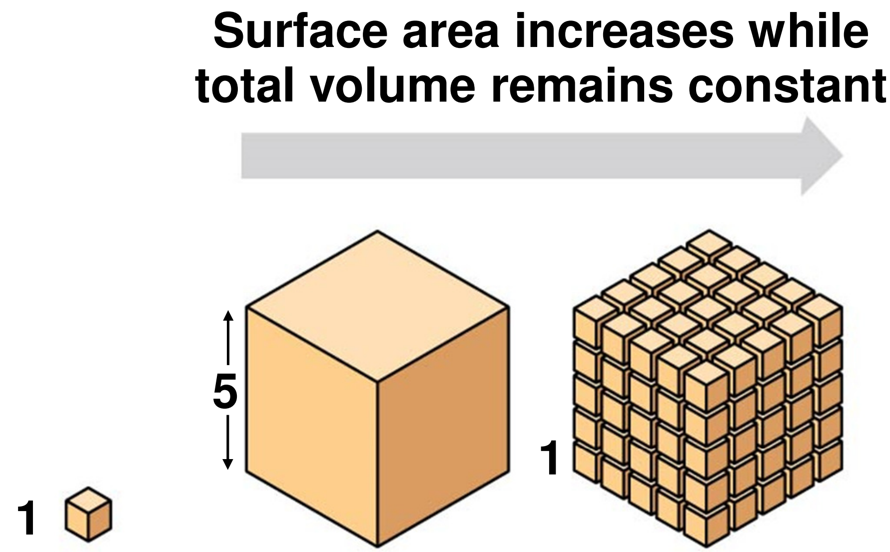
- The **plasma membrane** is a selective barrier that allows sufficient passage of oxygen, nutrients, and waste to service the volume of every cell
- The general structure of a biological membrane is a double layer of phospholipids



(a) TEM of a plasma membrane
Outside of cell
Inside of cell
0.1 µm
Carbohydrate side chains
Hydrophilic region
Hydrophobic region
Hydrophilic region
Phospholipid
Proteins
(b) Structure of the plasma membrane

- Metabolic requirements set upper limits on the size of cells
- The ratio of surface area to volume of a cell is critical!
- As the surface area increases by a factor of n^2, the volume increases by a factor of n^3
- Small cells have a greater surface area relative to volume
- Larger organisms do not generally have *larger* cells; they have *more* cells
- Microvilli increase surface area without an appreciable increase in volume

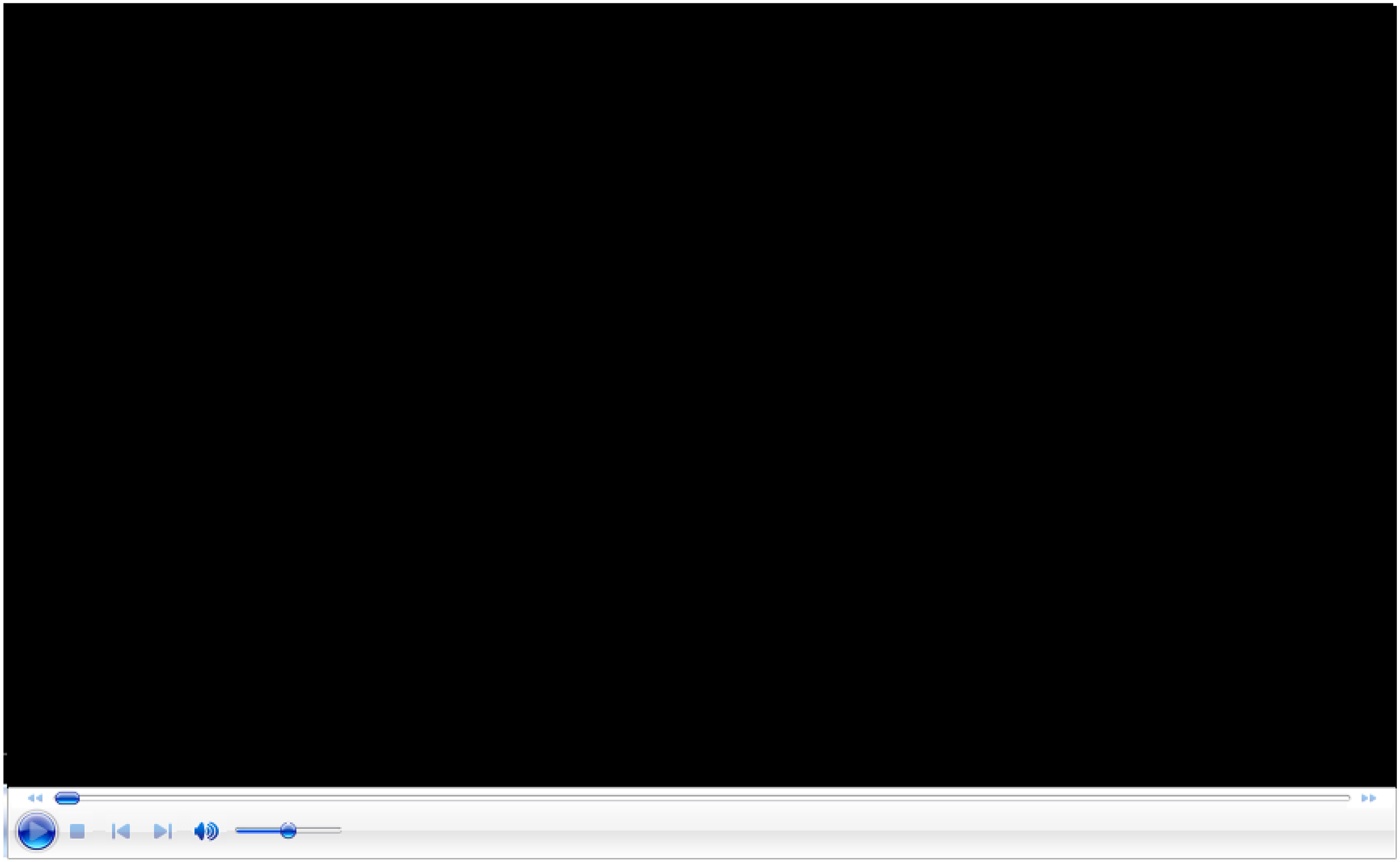
Figure 4.6



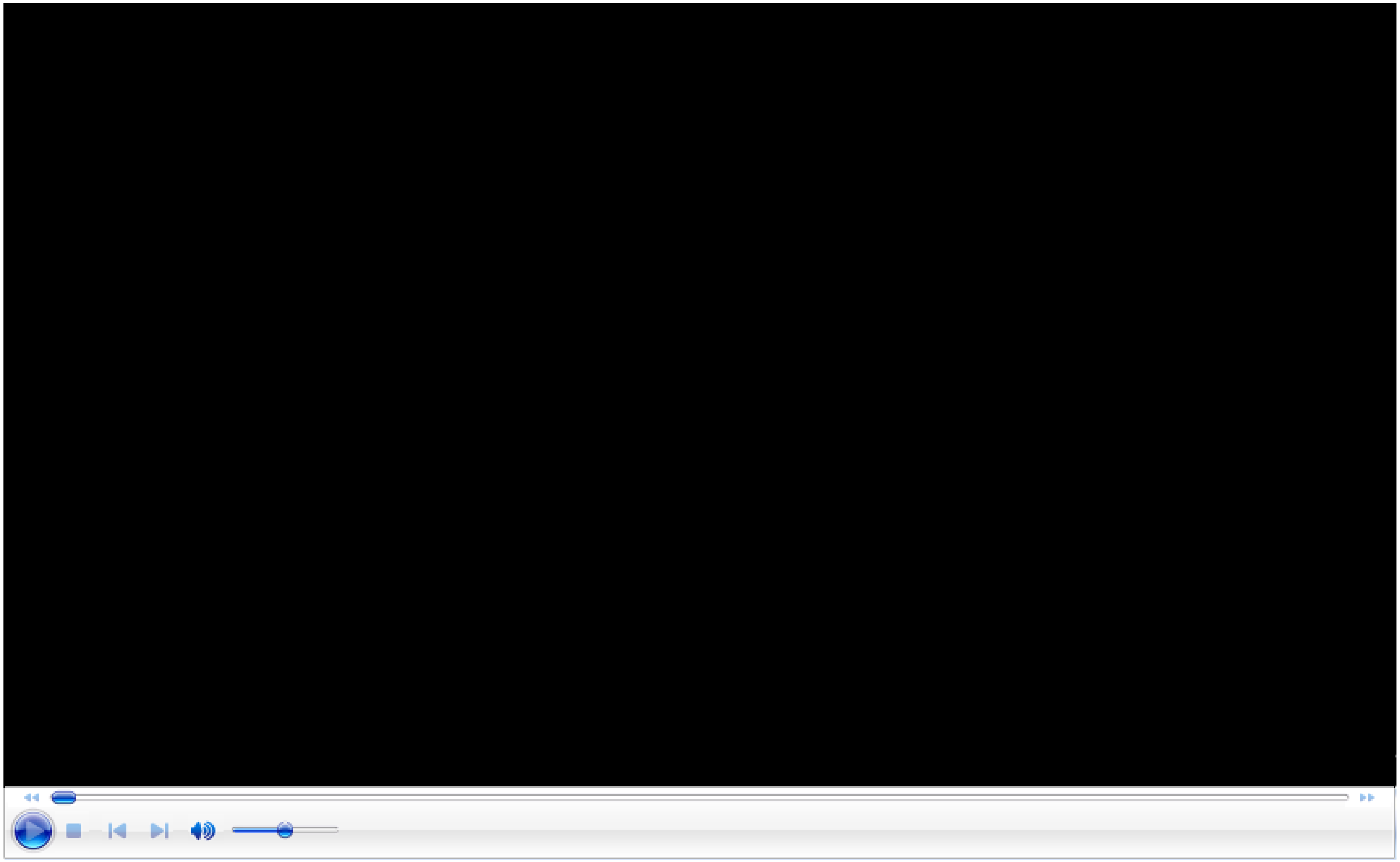
Total surface area [sum of the surface areas (height × width) of all box sides × number of boxes]	6	150	750
Total volume [height × width × length × number of boxes]	1	125	125
Surface-to-volume ratio [surface area ÷ volume]	6	1.2	6

A Panoramic View of the Eukaryotic Cell

- A eukaryotic cell has internal membranes that divide the cell into compartments—organelles
- The plasma membrane and organelle membranes participate directly in the cell's metabolism
- Most membranes are made of a double layer of phospholipids which contain embedded proteins

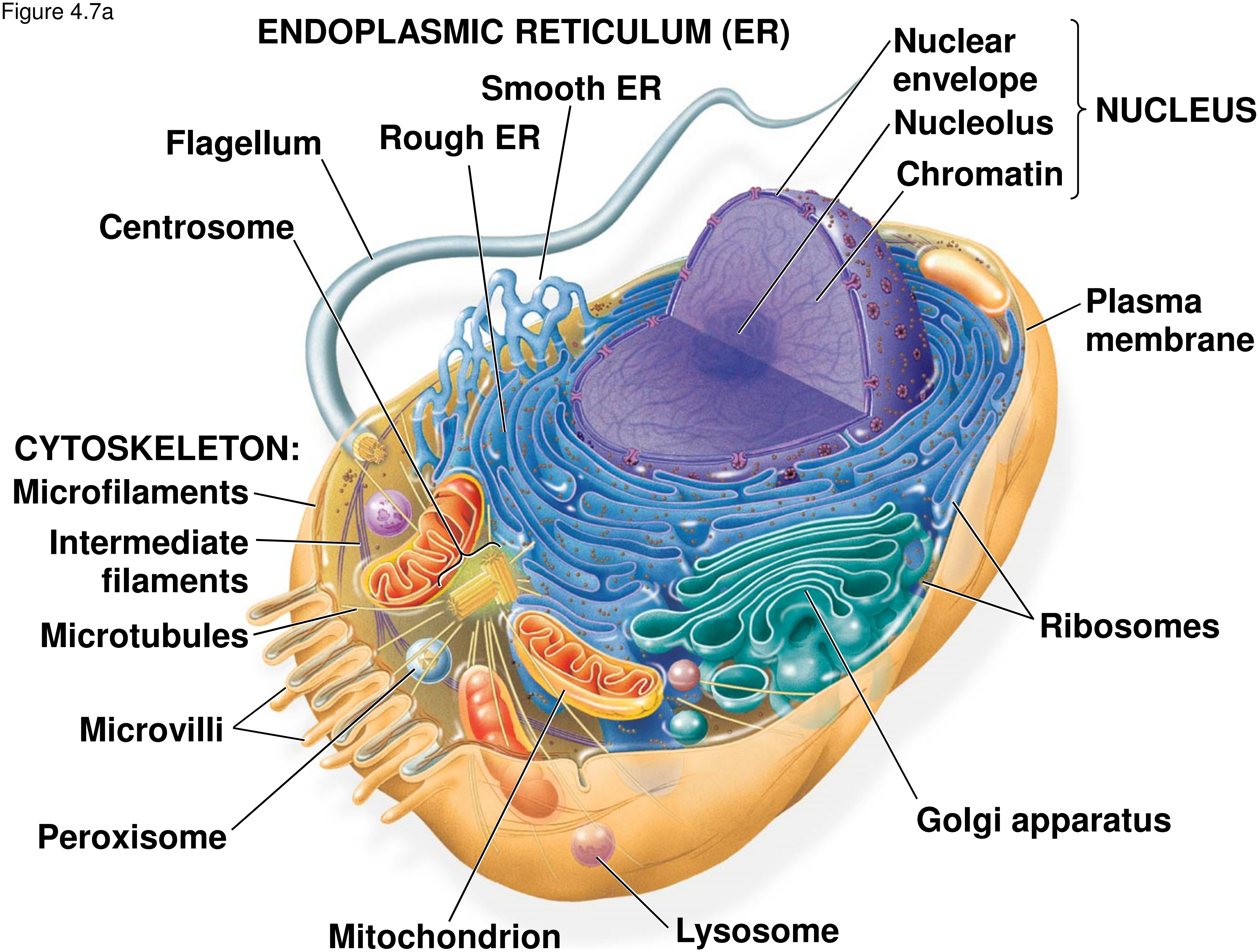


Video: Tour of an Animal Cell



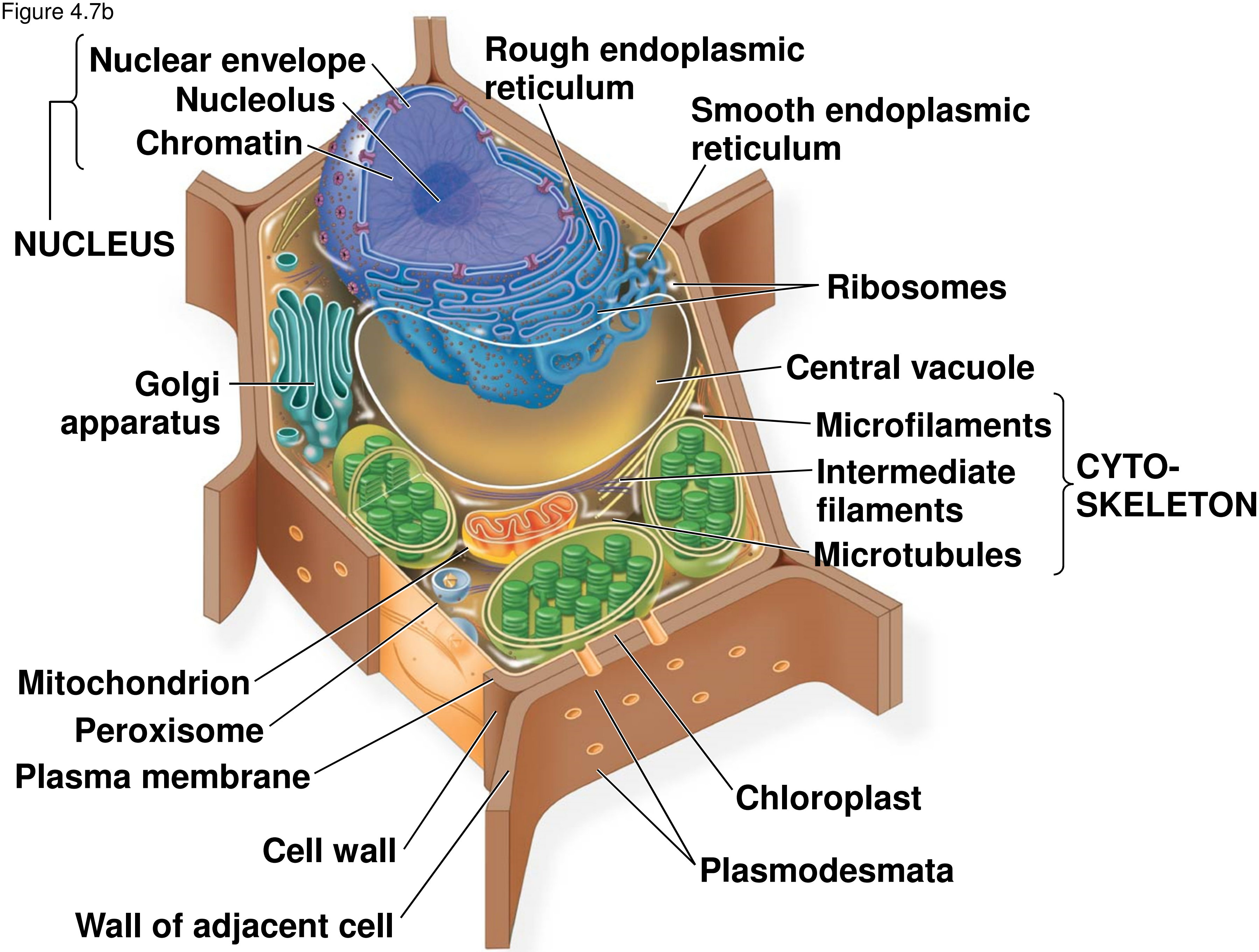
Video: Tour of a Plant Cell

Figure 4.7a



ENDOPLASMIC RETICULUM (ER)
Smooth ER
Rough ER
Flagellum
Centrosome
CYTOSKELETON:
Microfilaments
Intermediate filaments
Microtubules
Microvilli
Peroxisome
Mitochondrion
Lysosome
Golgi apparatus
Ribosomes
Plasma membrane
Nuclear envelope
Nucleolus
Chromatin
NUCLEUS

Figure 4.7b



NUCLEUS
Nuclear envelope
Nucleolus
Chromatin
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Ribosomes
Central vacuole
Golgi apparatus
Microfilaments
Intermediate filaments
Microtubules
CYTO-SKELETON
Mitochondrion
Peroxisome
Plasma membrane
Cell wall
Wall of adjacent cell
Chloroplast
Plasmodesmata

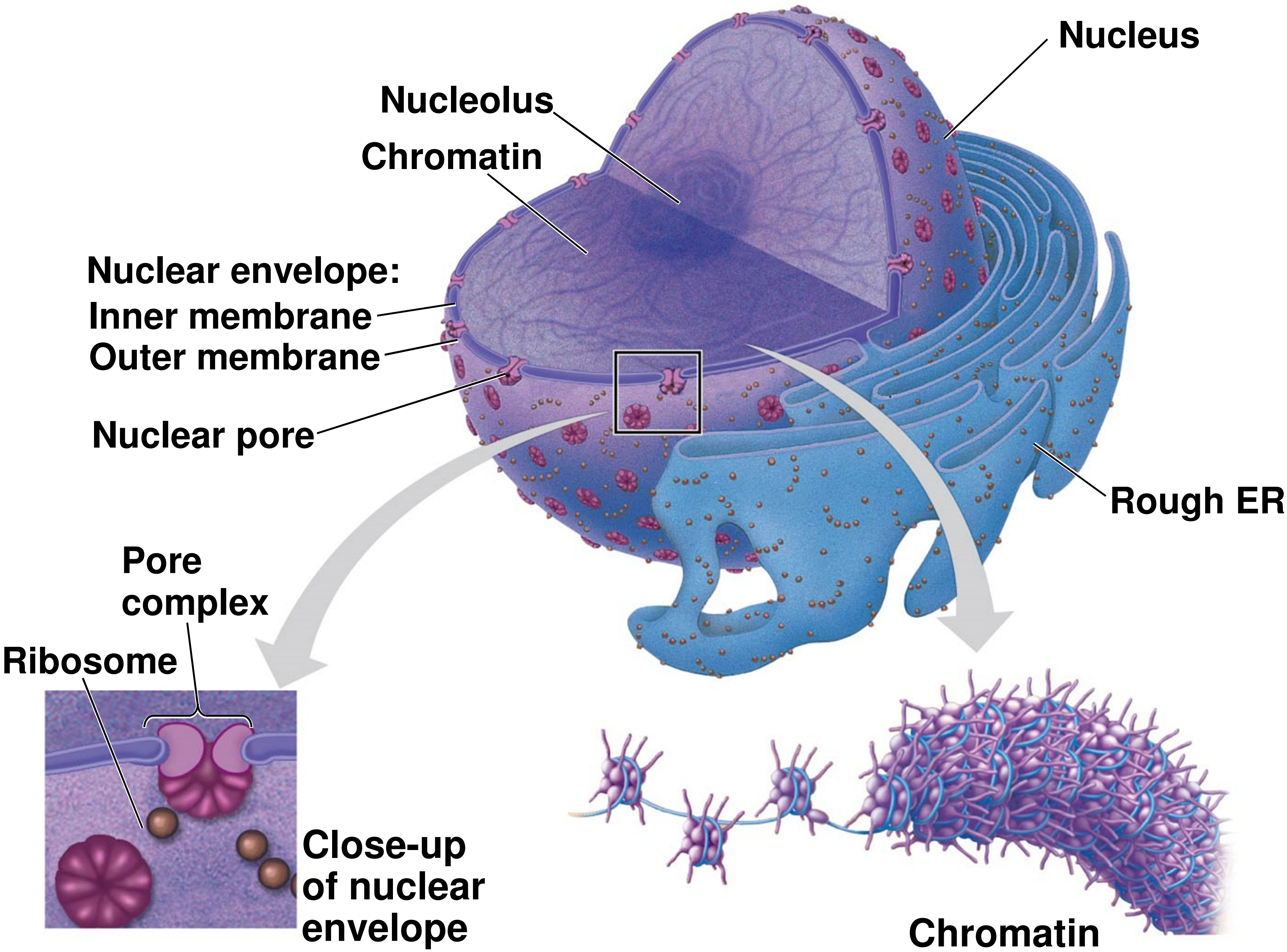
Concept 4.3: The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes

- The nucleus contains most of the DNA in a eukaryotic cell
- Ribosomes use the information from the DNA to make proteins

The Nucleus: Information Central

- The **nucleus** contains most of the cell's genes
  - Note: Some genes are located in mitochondria and chloroplasts
- The **nuclear envelope** encloses the nucleus, separating it from the cytoplasm
- The nuclear membrane is a double membrane; each membrane consists of a lipid bilayer
- Pores regulate the entry and exit of molecules from the nucleus
- The shape of the nucleus is maintained by the **nuclear lamina**, which is composed of protein

Figure 4.8a



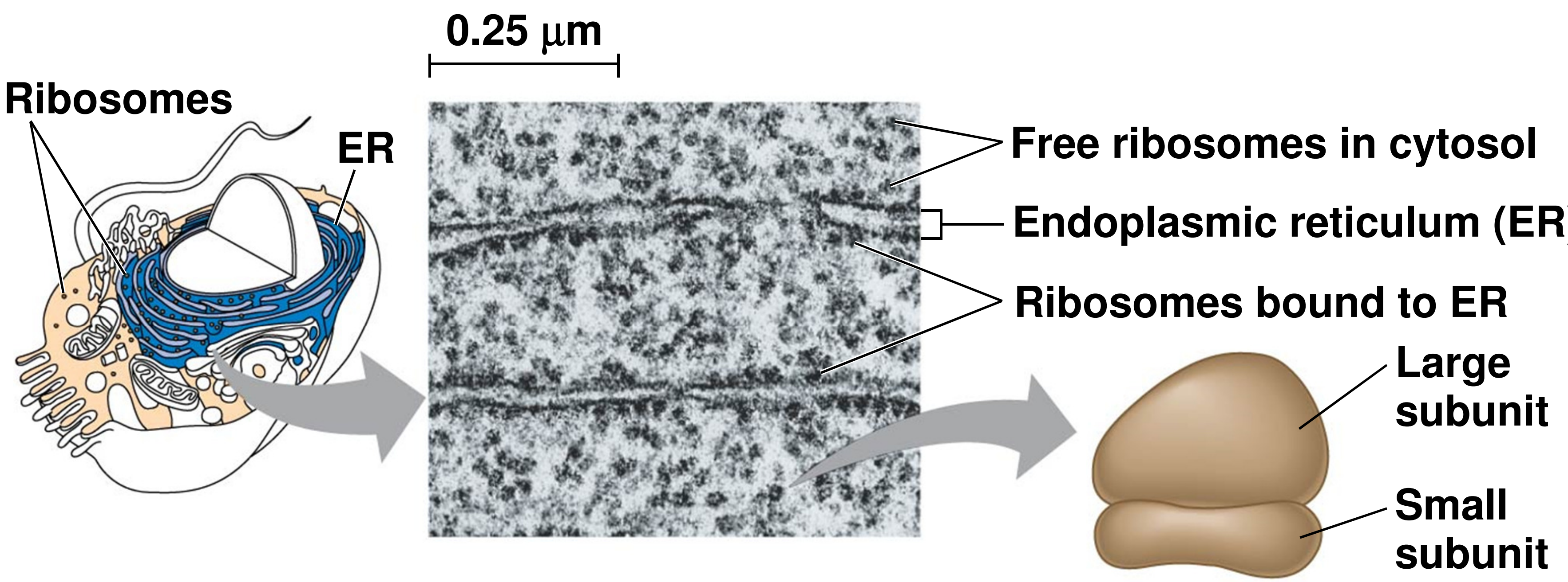
Nucleus
Nucleolus
Chromatin
Nuclear envelope:
Inner membrane
Outer membrane
Nuclear pore
Rough ER
Pore complex
Ribosome
Close-up of nuclear envelope
Chromatin

- In the nucleus, DNA is organized into discrete units called **chromosomes**
  - Each chromosome is one long DNA molecule associated with proteins
- The DNA and proteins of chromosomes are together called **chromatin**
  - Chromatin condenses to form discrete chromosomes as a cell prepares to divide
- The **nucleolus** is located within the nucleus and is the site of ribosomal RNA (rRNA) synthesis

Ribosomes: Protein Factories

- **Ribosomes** are complexes of ribosomal RNA and protein
- Ribosomes carry out protein synthesis in two locations
  - In the cytosol (free ribosomes)
  - On the outside of the endoplasmic reticulum or the nuclear envelope (bound ribosomes)

Figure 4.9



TEM showing ER and ribosomes

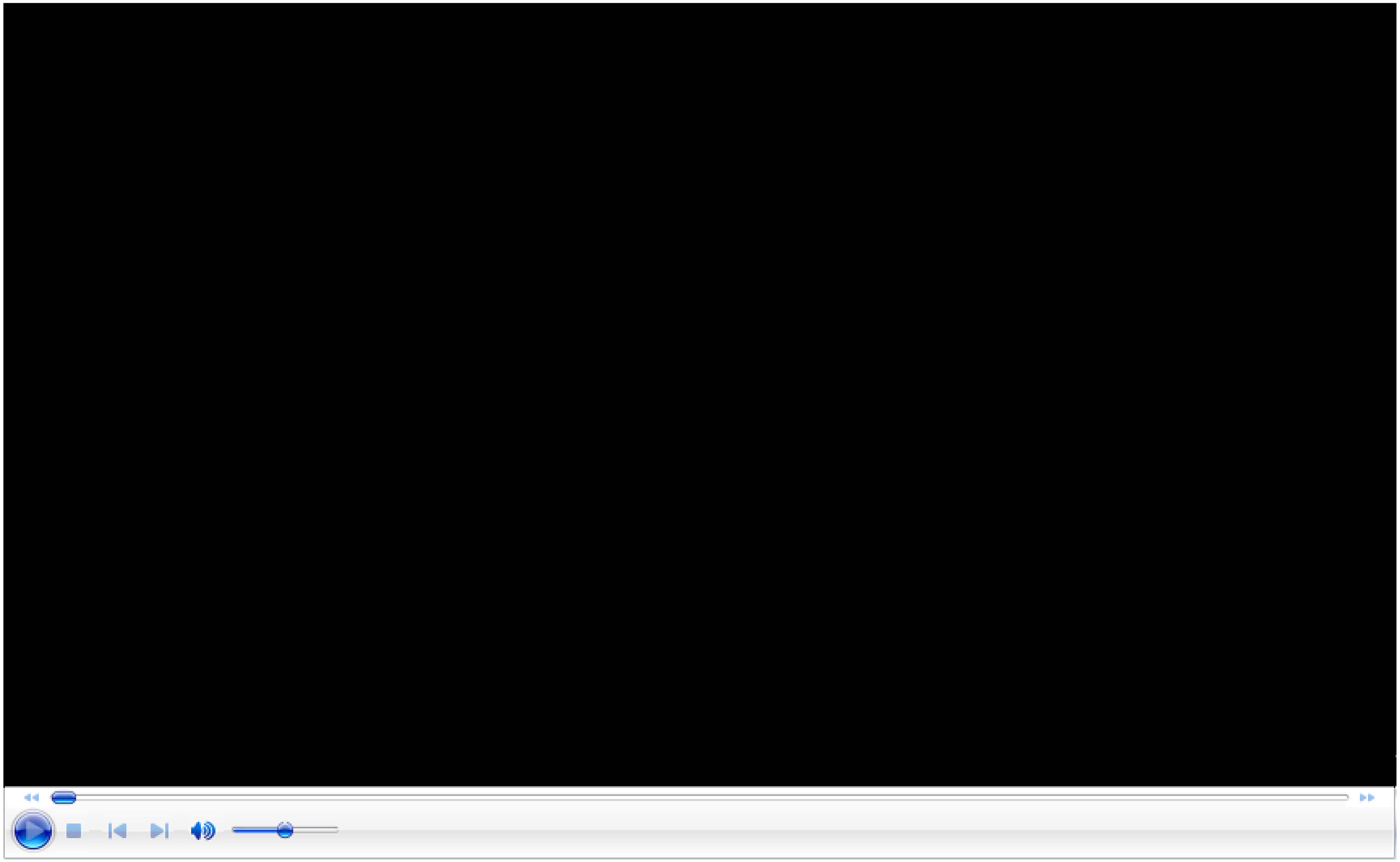
Diagram of a ribosome

Concept 4.4: The endomembrane system regulates protein traffic and performs metabolic functions in the cell

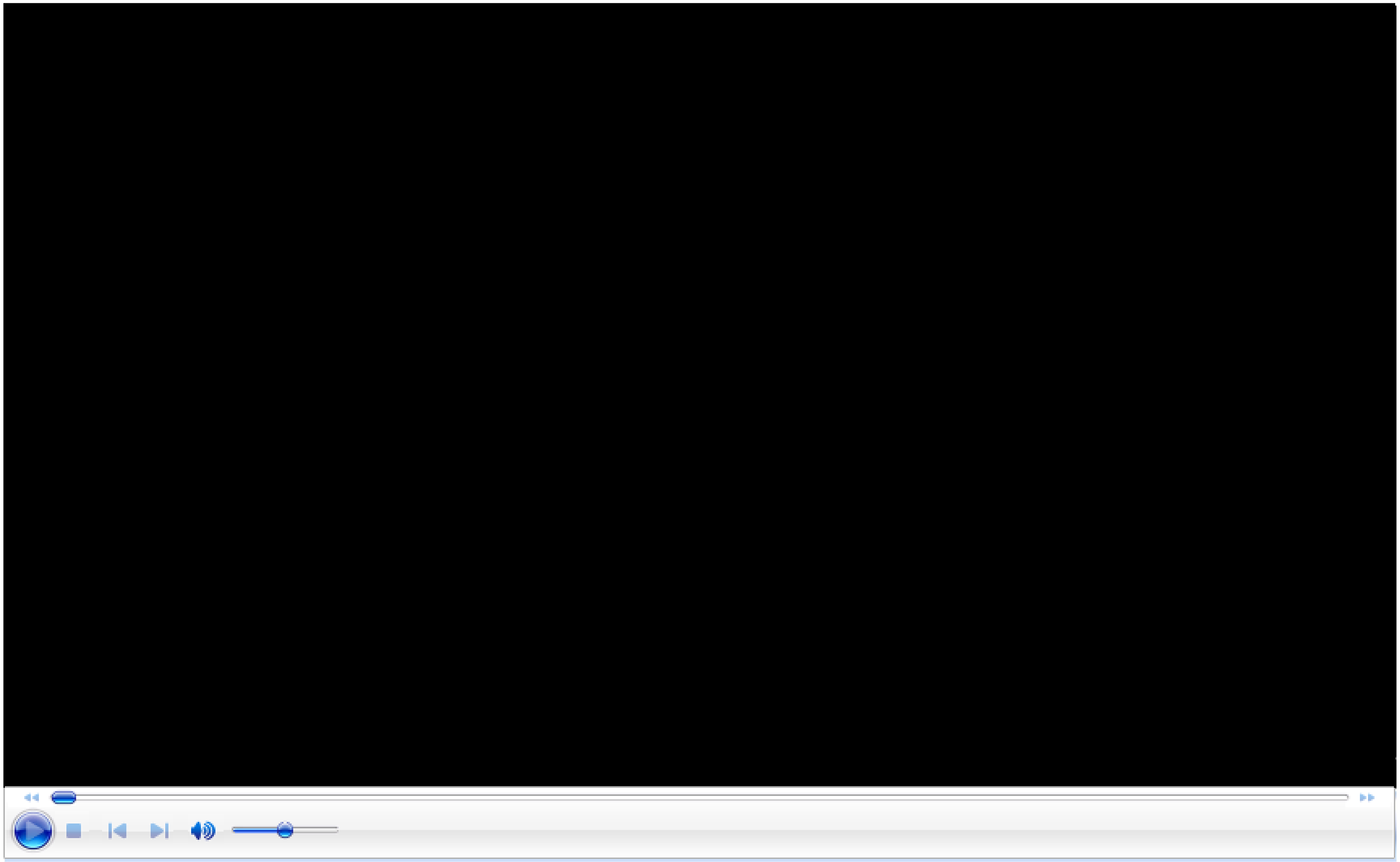
- Components of the **endomembrane system**
  - Nuclear envelope
  - Endoplasmic reticulum
  - Golgi apparatus
  - Lysosomes
  - Vacuoles
  - Plasma membrane
- These components are either continuous or connected through transfer by **vesicles**

The Endoplasmic Reticulum: Biosynthetic Factory

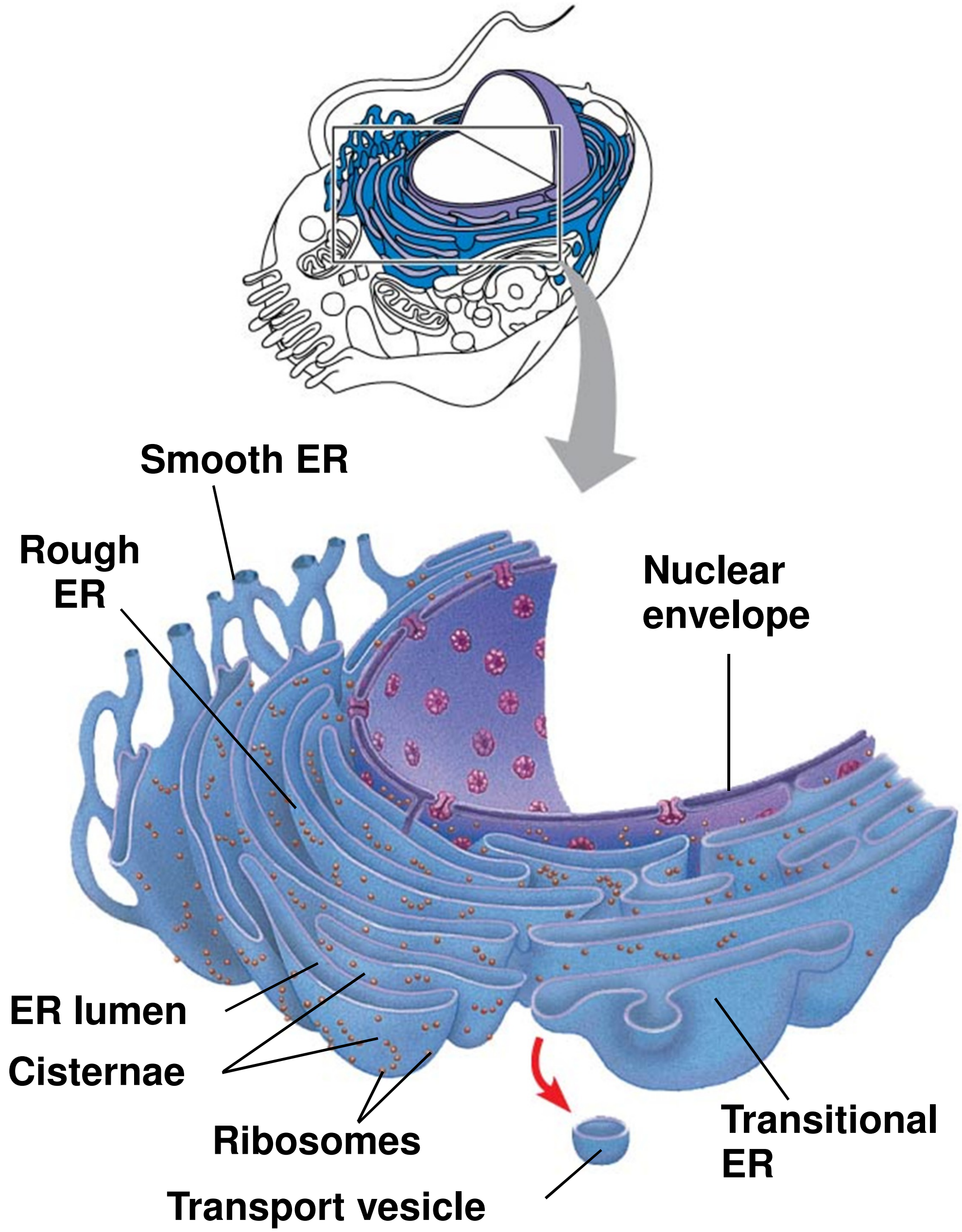
- The **endoplasmic reticulum (ER)** is an extensive network of membranes that is continuous with the nuclear envelope
- Cisternae
  - Network of membranous tubules and sacs
- ER lumen
  - Internal compartment of the ER (cavity)
- There are two distinct regions of ER
  - **Smooth ER**: lacks ribosomes
  - **Rough ER**: surface is studded with ribosomes



Video: Endoplasmic Reticulum



Video: ER and Mitochondria



Smooth ER
Rough ER
Nuclear envelope
ER lumen
Cisternae
Ribosomes
Transport vesicle
Transitional ER

Functions of Smooth ER

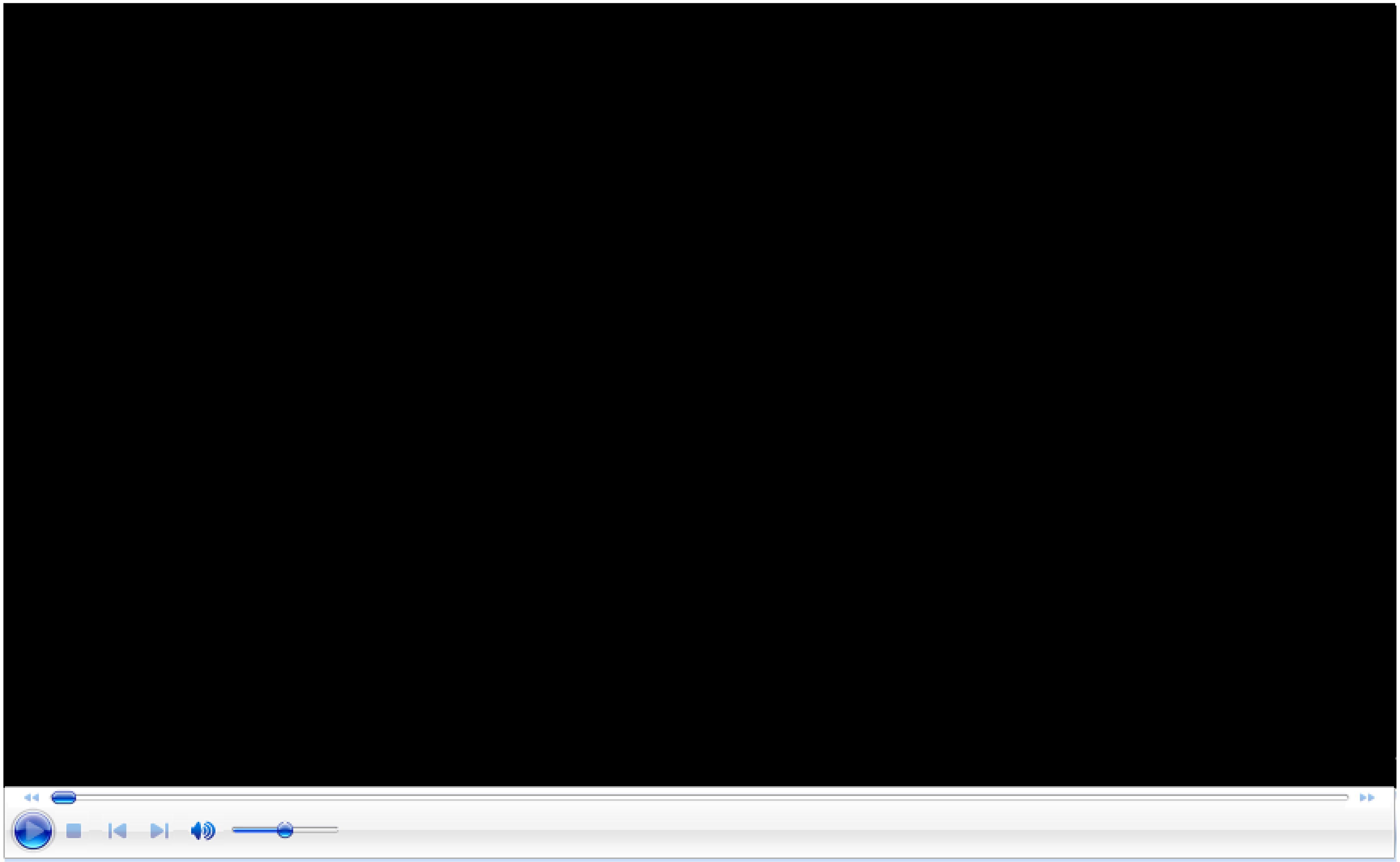
- The smooth ER
  - Synthesizes lipids
  - Metabolizes carbohydrates
  - Detoxifies drugs and poisons
  - Stores calcium ions

Functions of Rough ER

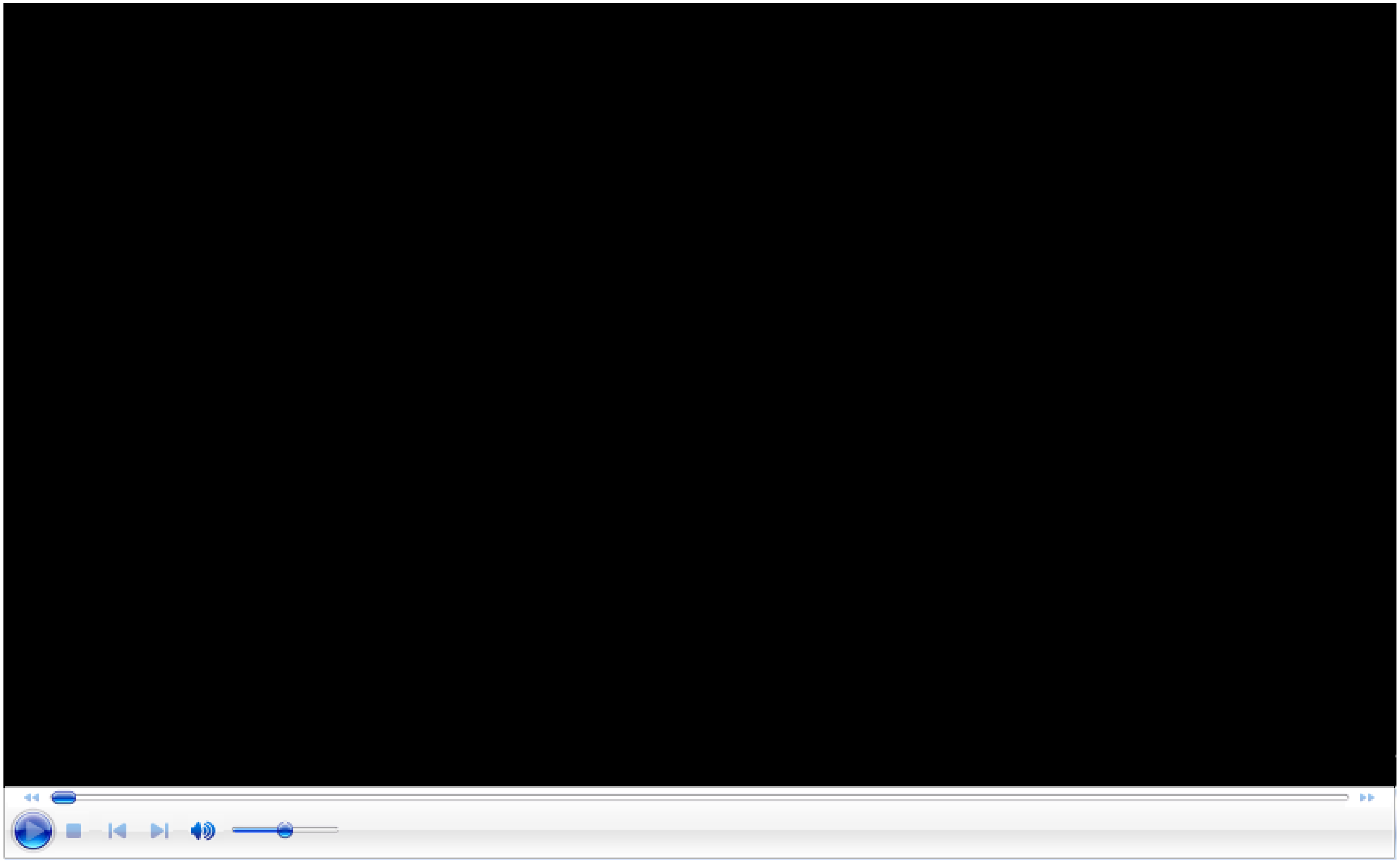
- The rough ER
  - Has bound ribosomes, which secrete **glycoproteins** (proteins covalently bonded to carbohydrates)
  - Distributes **transport vesicles,** proteins surrounded by membranes
  - Is a membrane factory for the cell

The Golgi Apparatus: Shipping and Receiving Center

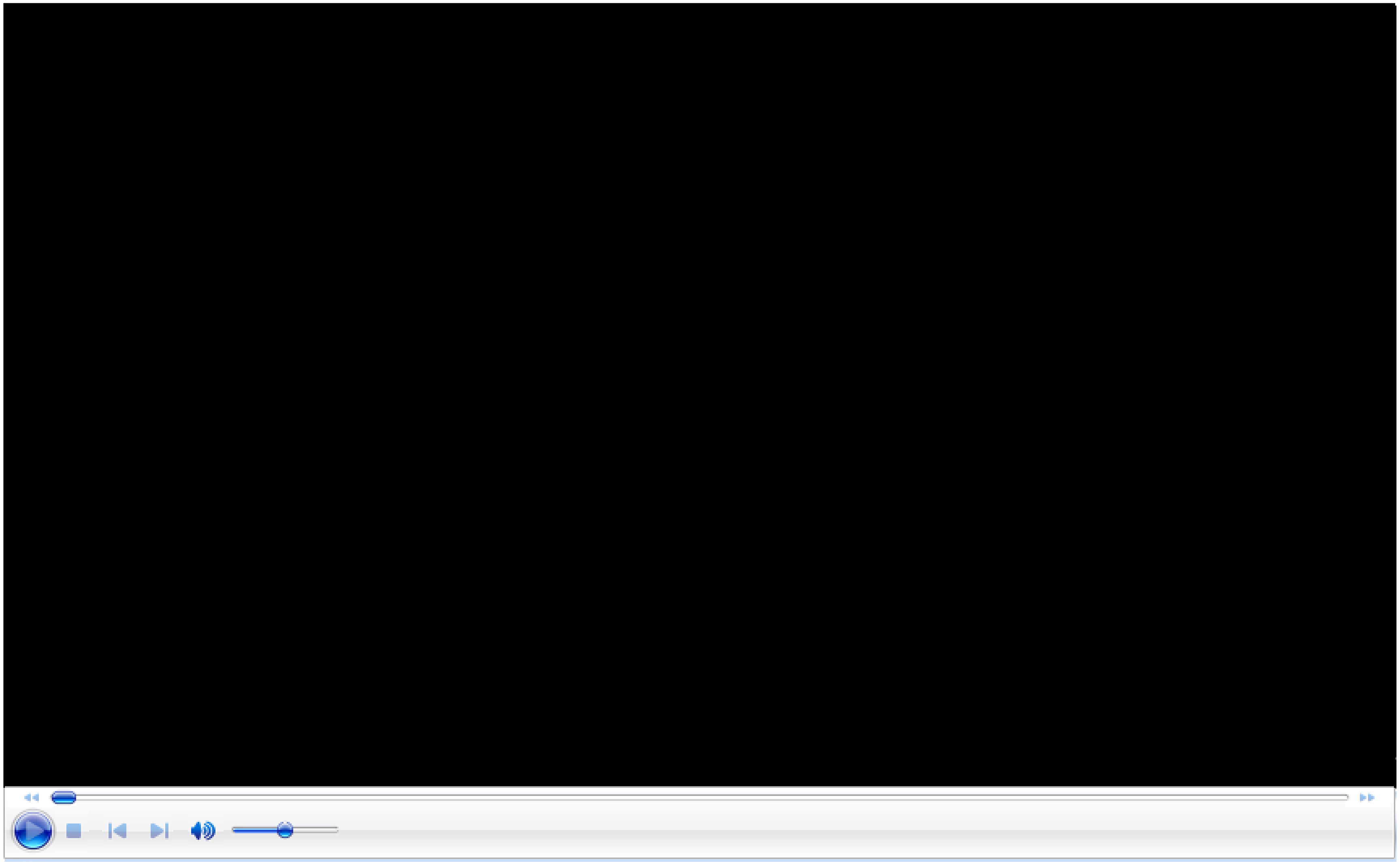
- The **Golgi apparatus** consists of flattened membranous sacs called cisternae
- Functions of the Golgi apparatus
  - Modifies products of the ER
  - Manufactures certain macromolecules
  - Sorts and packages materials into transport vesicles
- Two sides of Golgi stack
  - *Cis* face-receiving
    - Located near ER
  - *Trans* face-shipping
    - Gives rise to vesicles



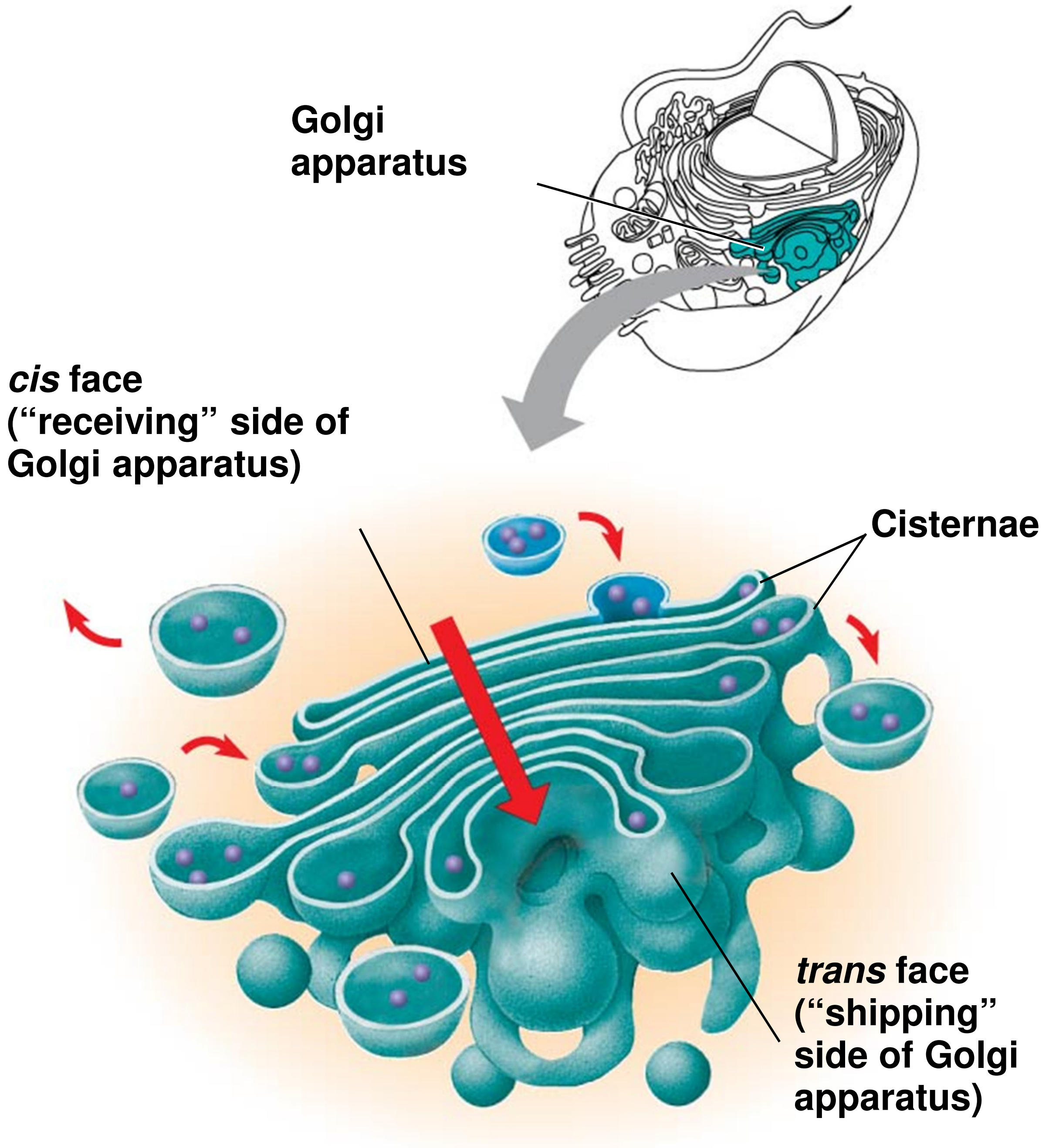
Video: ER to Golgi Traffic



Video: Golgi 3-D



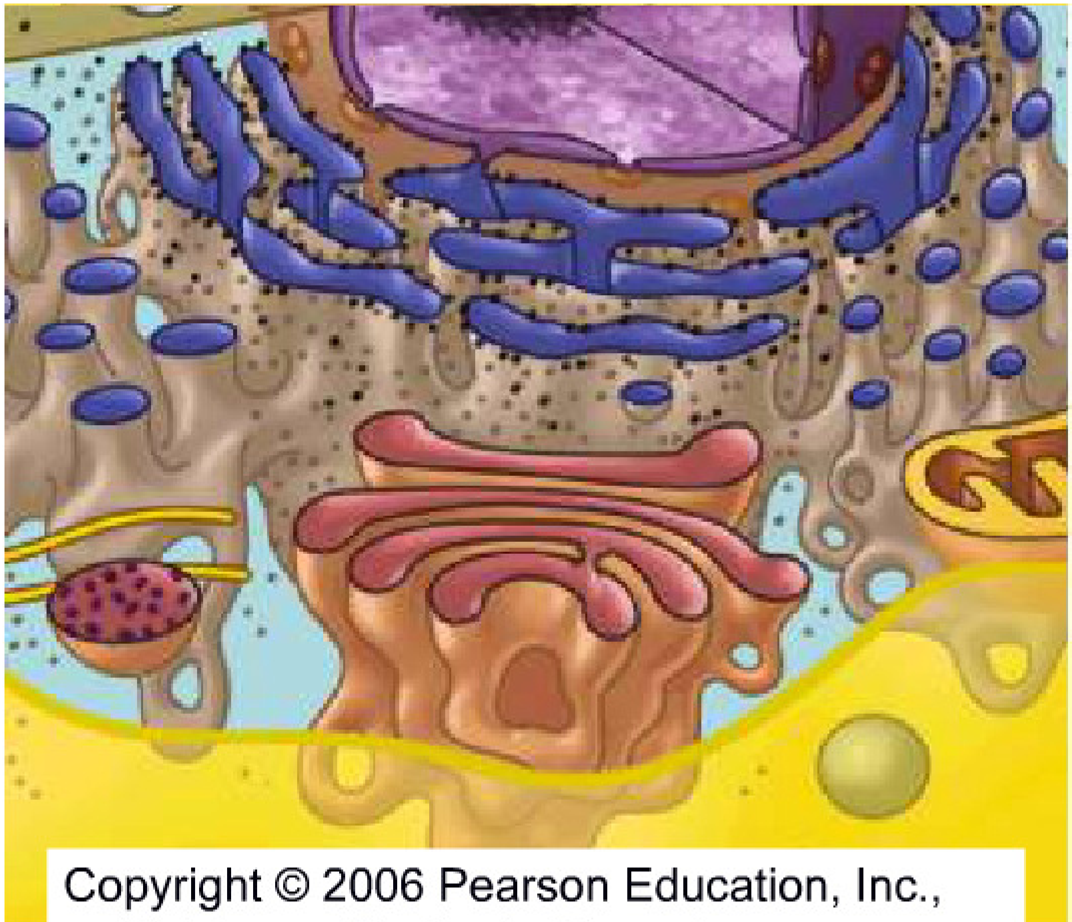
Video: Golgi Secretion


Golgi apparatus
cis face (“receiving” side of Golgi apparatus)
Cisternae
trans face (“shipping” side of Golgi apparatus)

Lysosomes: Digestive Compartments

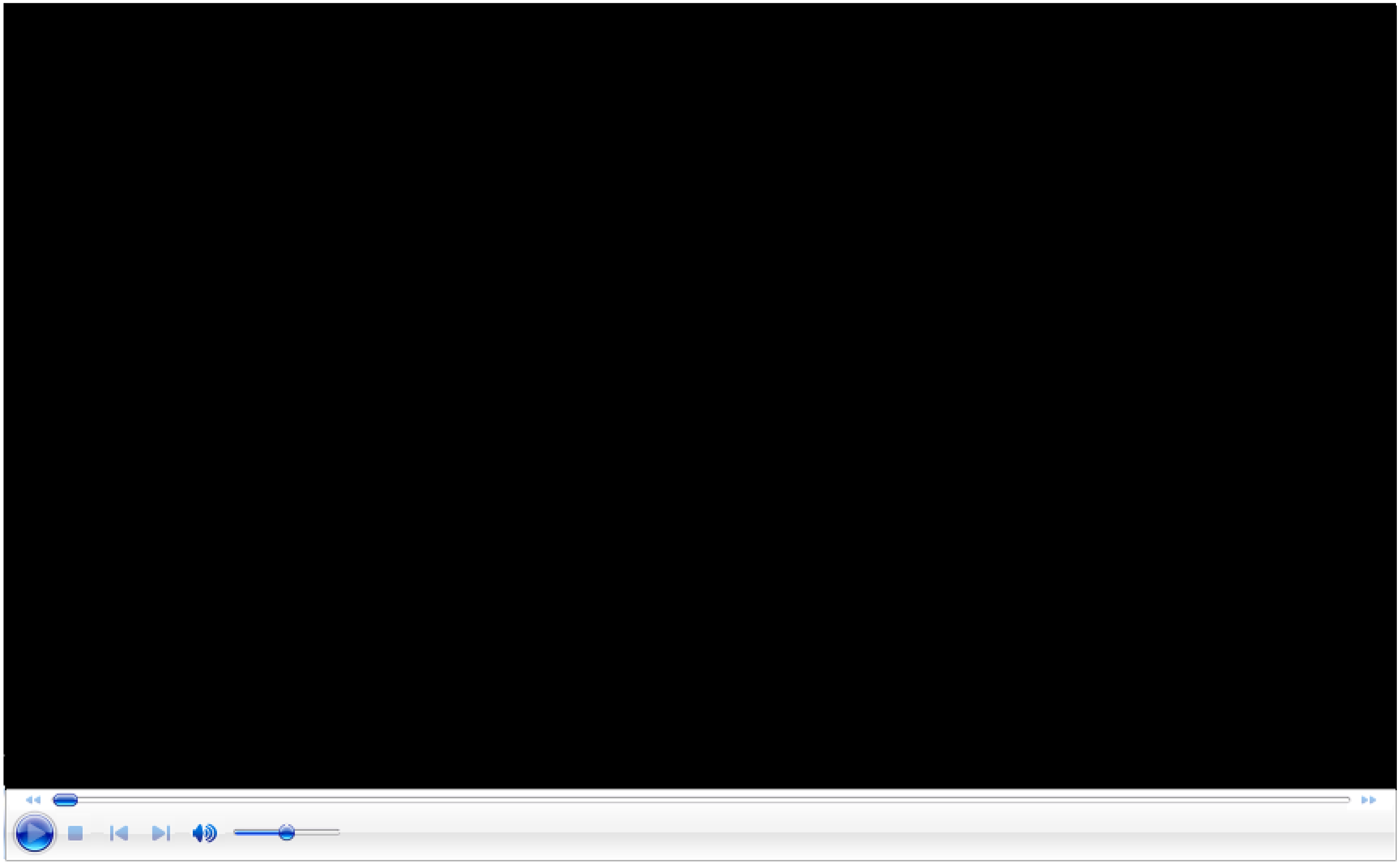
- A **lysosome** is a membranous sac of hydrolytic enzymes that can digest macromolecules
- Lysosomal enzymes can hydrolyze proteins, fats, polysaccharides, and nucleic acids
  - Lysosomal enzymes work best in the <u>acidic</u> environment inside the lysosome

- Some types of cell can engulf another cell by **phagocytosis**; this forms a food vacuole
  - A lysosome fuses with the food vacuole and digests the molecules
- Lysosomes also use enzymes to recycle the cell's own organelles and macromolecules, a process called *autophagy*

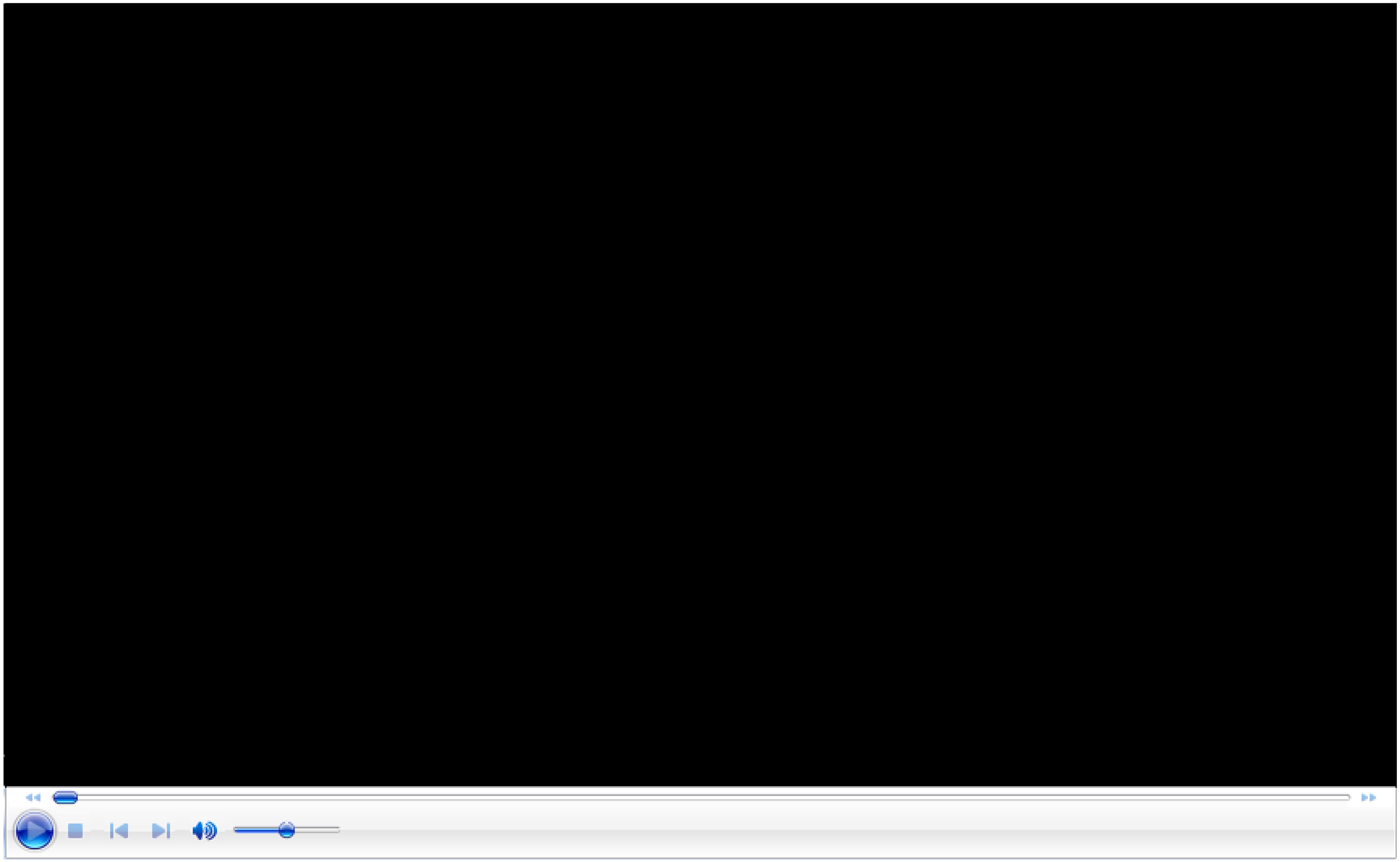


Animation: Lysosome Formation

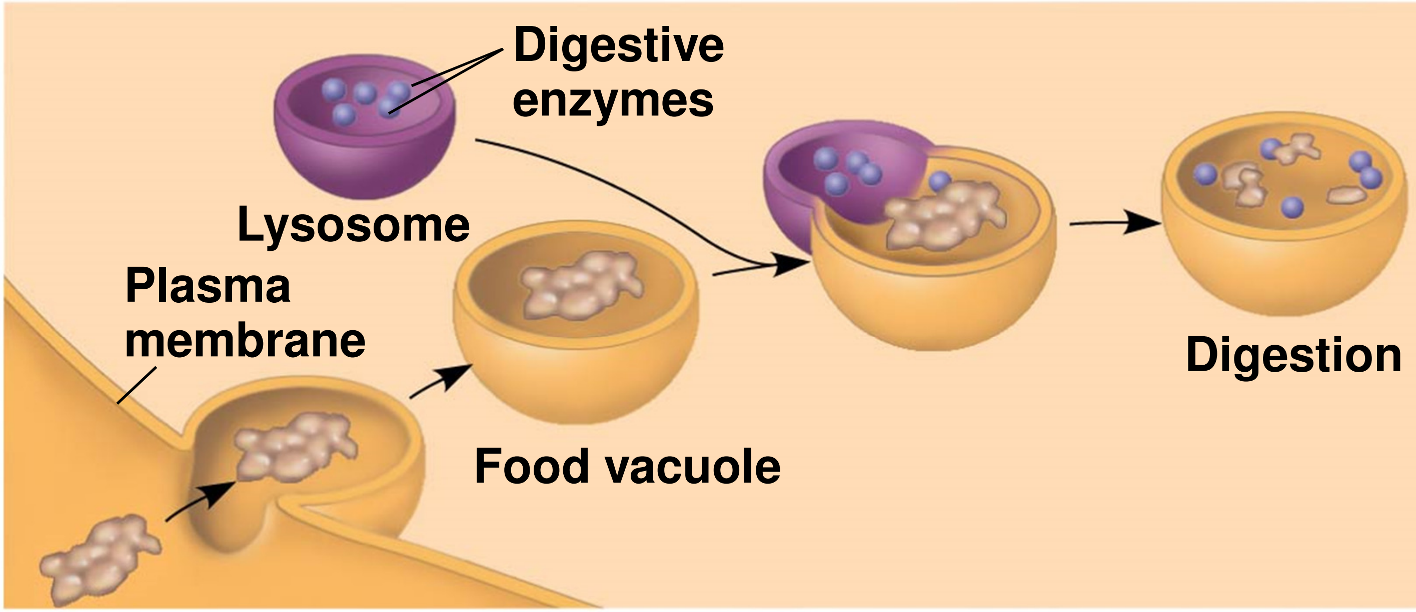
Right click slide / Select play



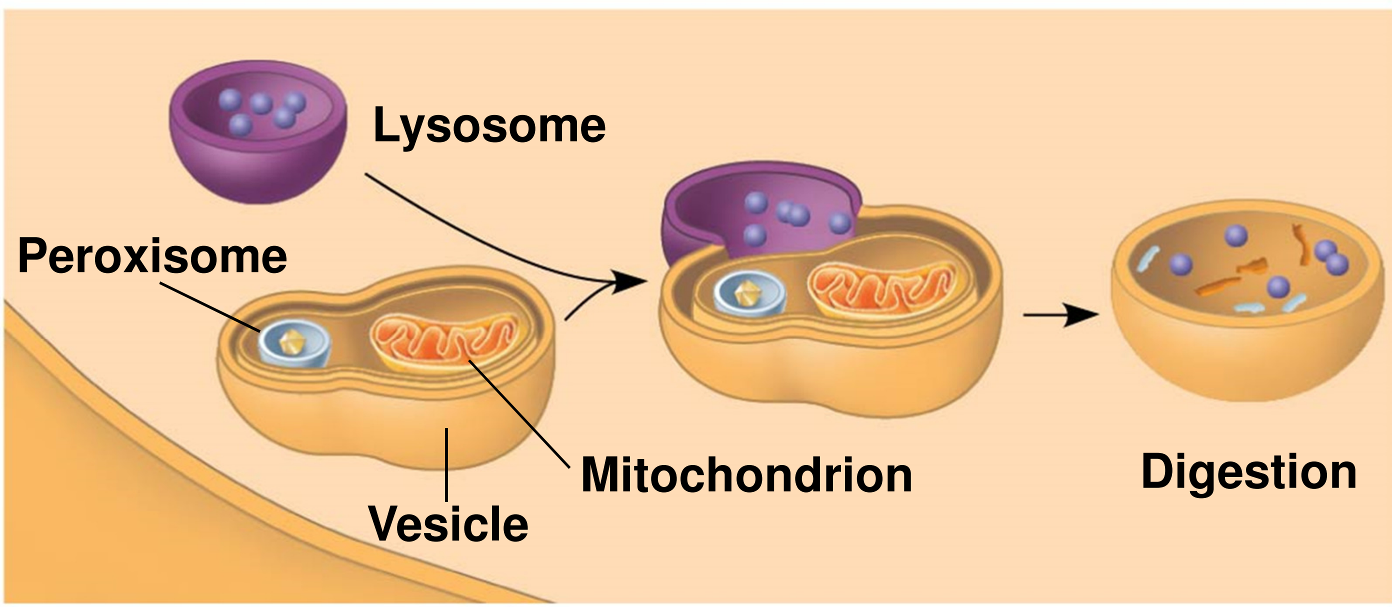
Video: Phagocytosis



Video: *Paramecium* Vacuole



Lysosomes: Phagocytosis



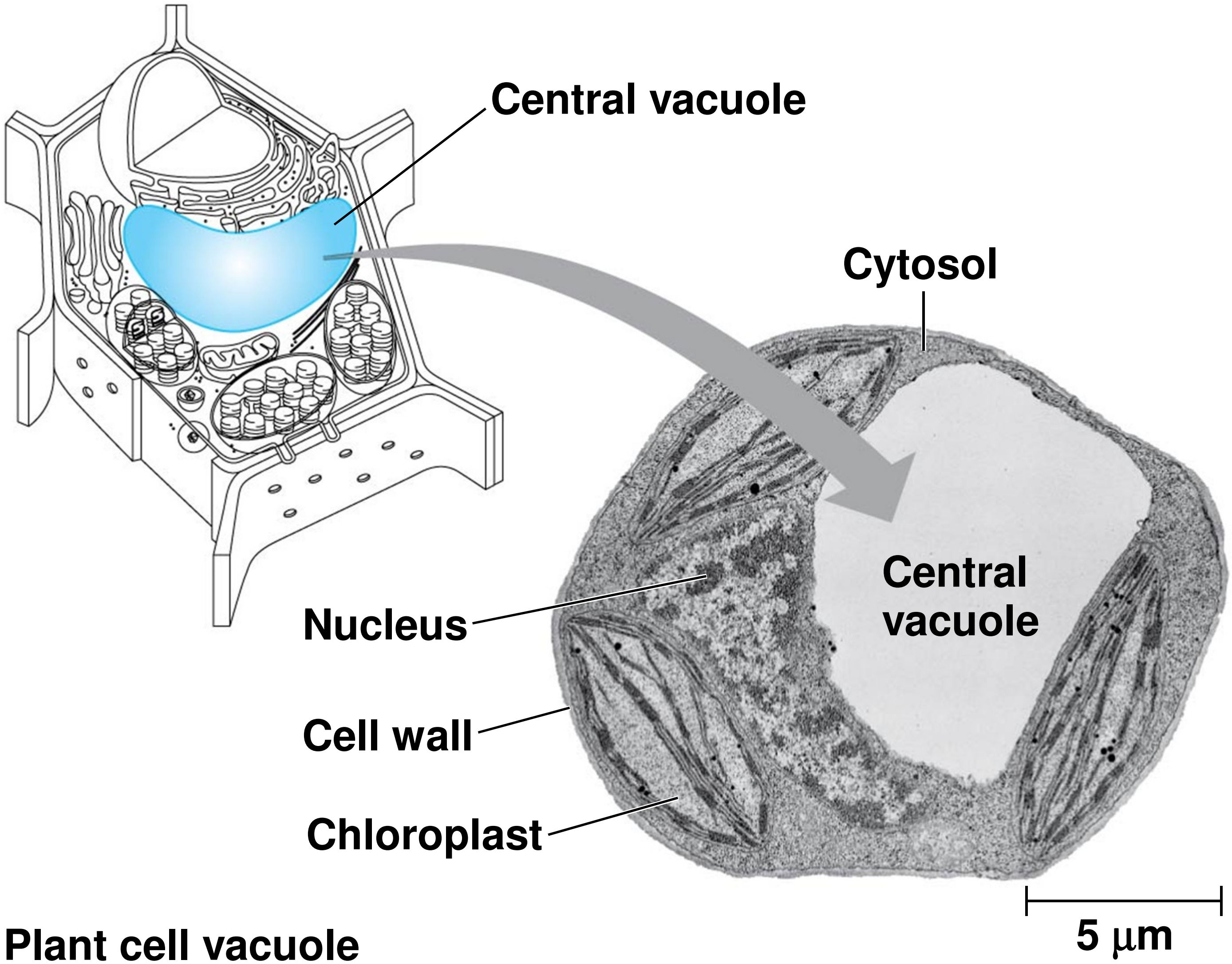
Lysosomes: Autophagy

Vacuoles: Diverse Maintenance Compartments

- **Vacuoles** are large vesicles derived from the endoplasmic reticulum and Golgi apparatus
  - **Food vacuoles** are formed by phagocytosis
  - **Contractile vacuoles**, found in many freshwater protists, pump excess water out of cells
  - **Central vacuoles**, found in many mature plant cells, hold organic compounds and water

- Certain vacuoles in plants and fungi carry out enzymatic hydrolysis like lysosomes
- Vacuoles may also help protect plants against herbivores by storing poisonous or unpalatable compounds
- Some contain pigments useful in attracting pollinators
- Central vacuole plays a major role in the growth of plant cells, which enlarge as the vacuole absorbs water

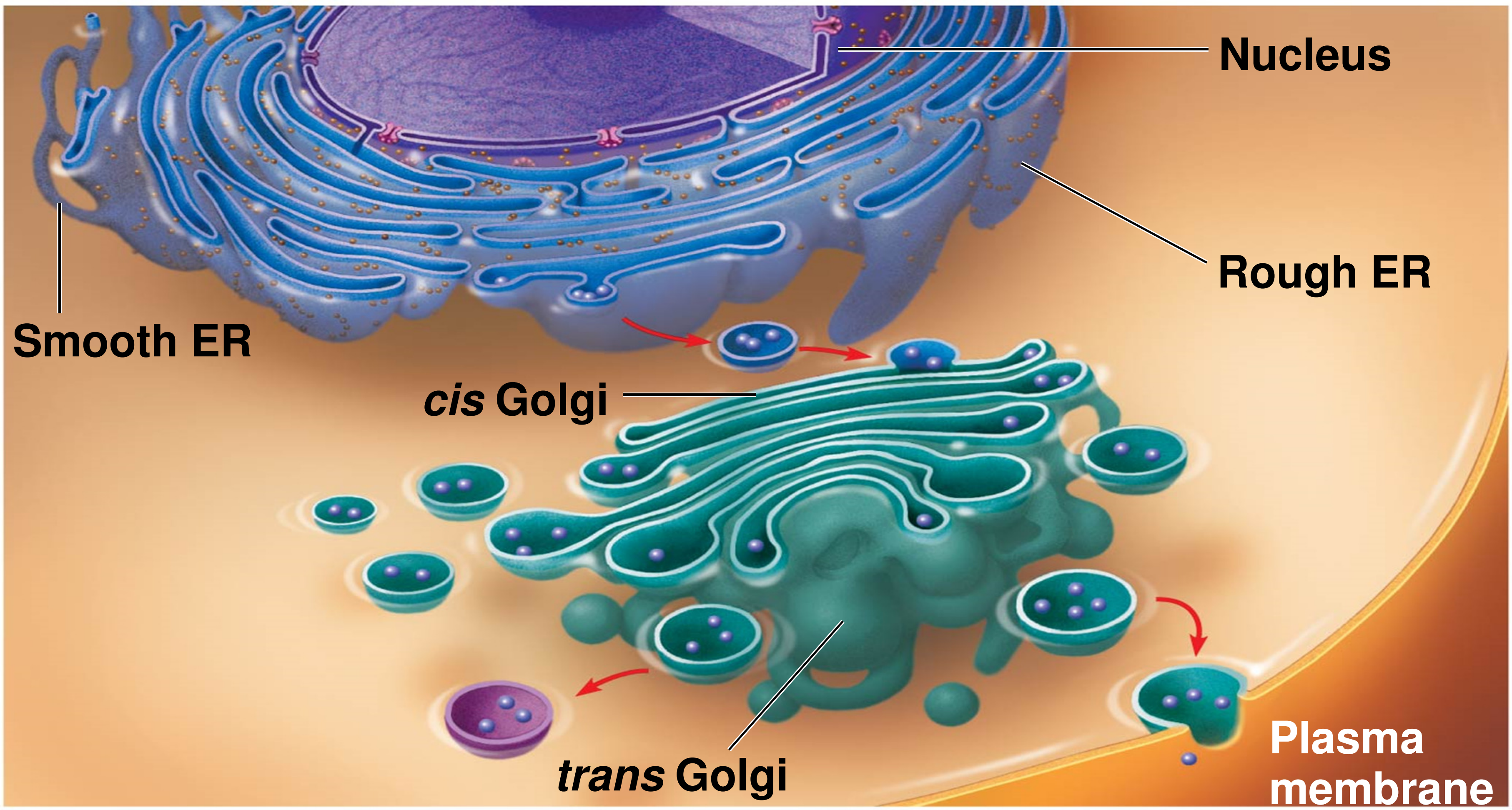
Figure 4.14



Plant cell vacuole

The Endomembrane System: *A Review*

- The endomembrane system is a complex and dynamic player in the cell's compartmental organization



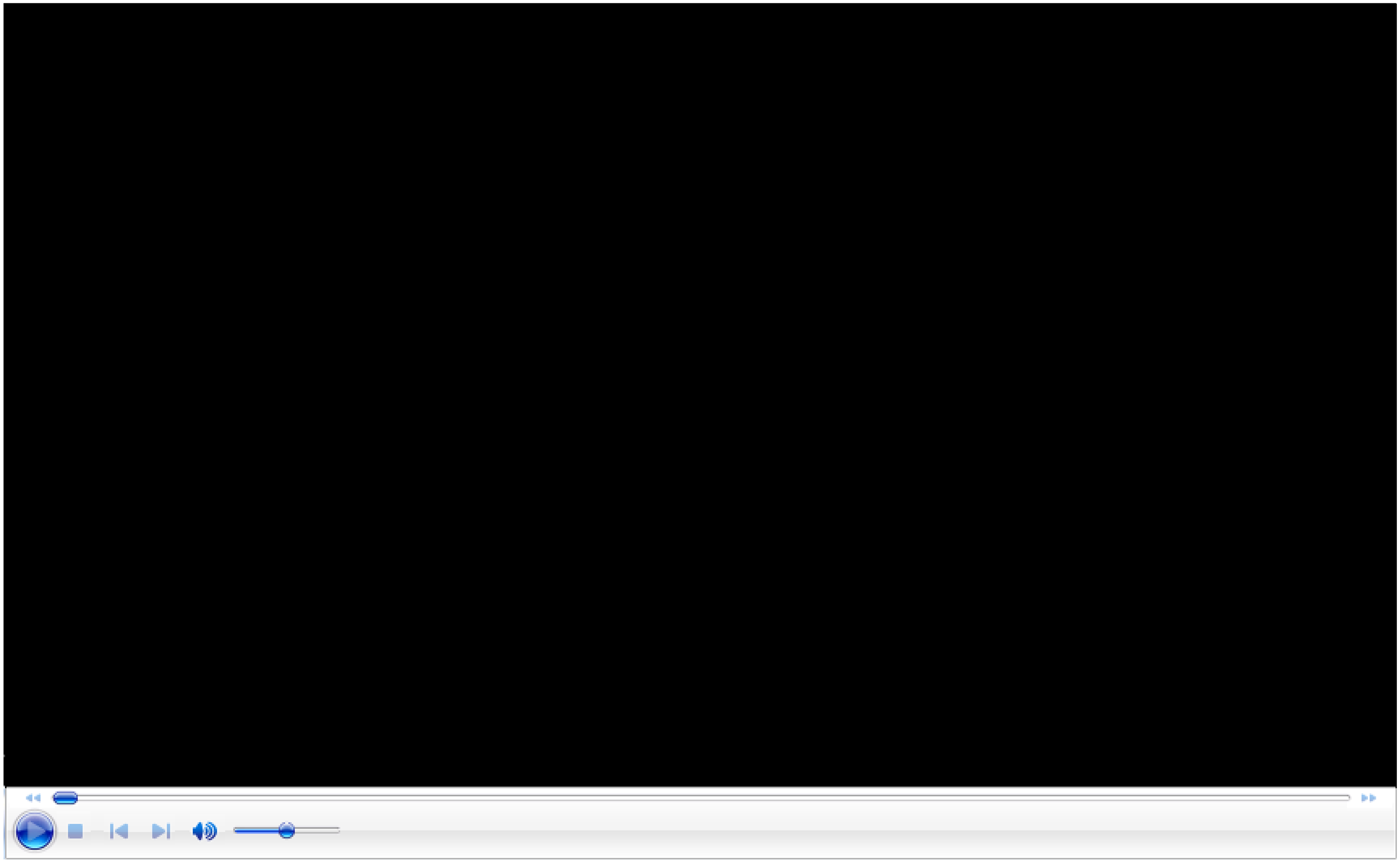
Concept 4.5: Mitochondria and chloroplasts change energy from one form to another

- **Mitochondria** are the sites of cellular respiration
  - Metabolic process that uses oxygen to generate ATP
- **Chloroplasts**, found in plants and algae, are the sites of photosynthesis
  - Convert solar energy to chemical energy
- Peroxisomes are oxidative organelles

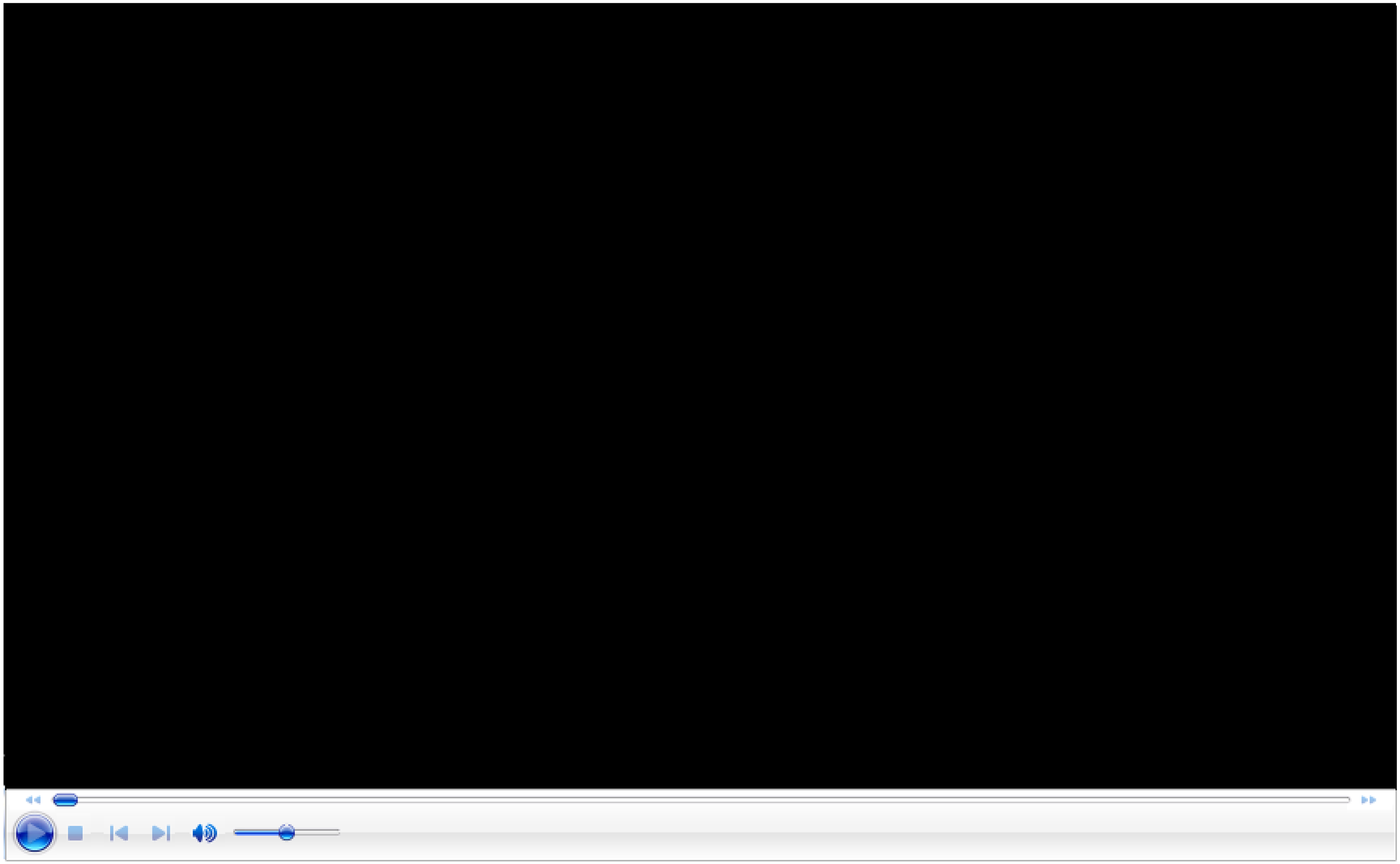
The Evolutionary Origins of Mitochondria and Chloroplasts

- Mitochondria and chloroplasts have similarities with bacteria
  - Enveloped by a double membrane
  - Contain free ribosomes and circular DNA molecules
  - Grow and reproduce somewhat independently in cells

- The **endosymbiont theory**
  - An early ancestor of eukaryotic cells engulfed an oxygen-using nonphotosynthetic prokaryotic cell, which formed an endosymbiont relationship with its host
  - The host cell and endosymbiont merged into a single organism, a eukaryotic cell with a mitochondrion
  - At least one of these cells may have taken up a photosynthetic prokaryote, becoming the ancestor of cells that contain chloroplasts

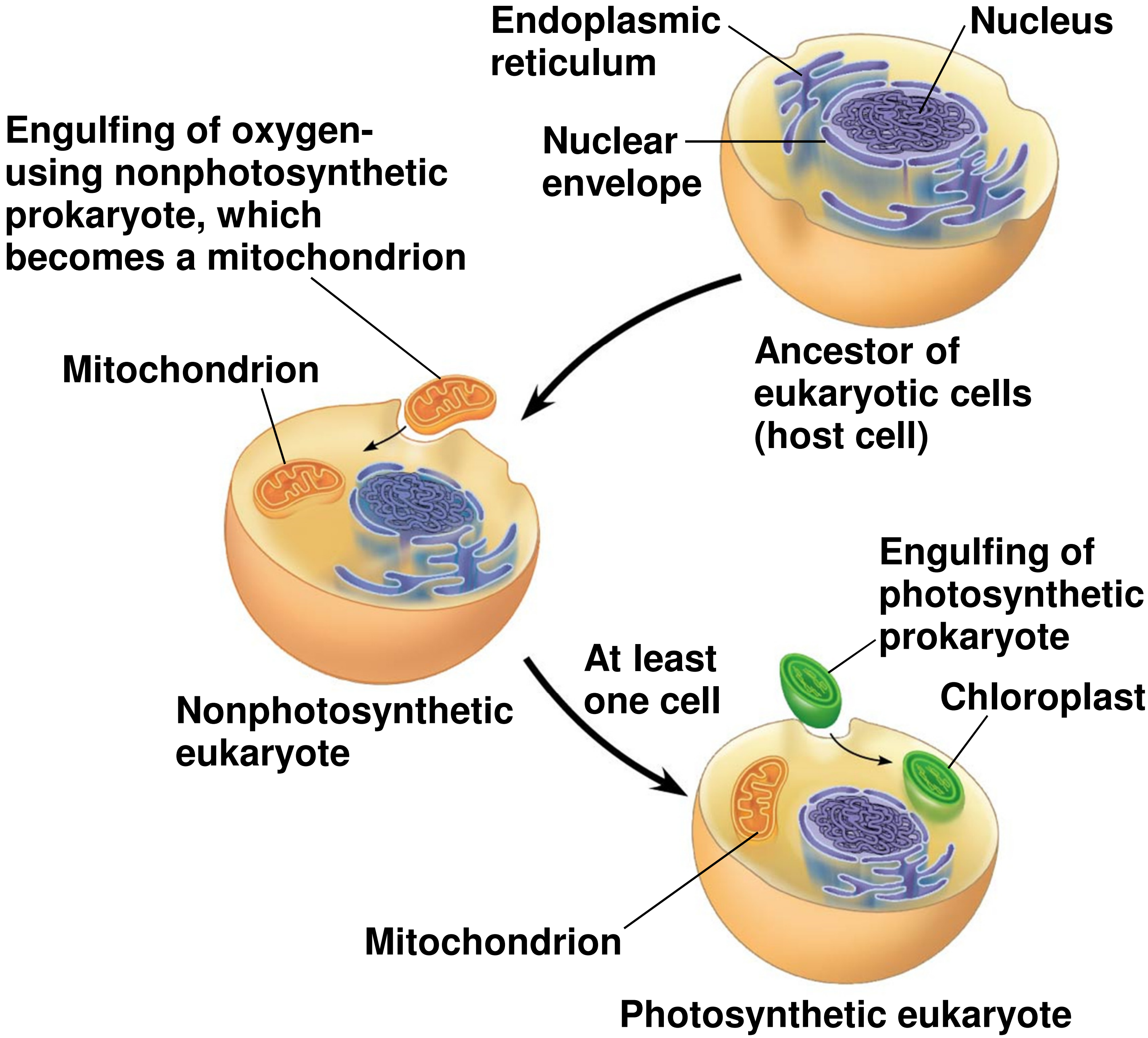


Video: ER and Mitochondria



Video: Mitochondria 3-D

Figure 4.16

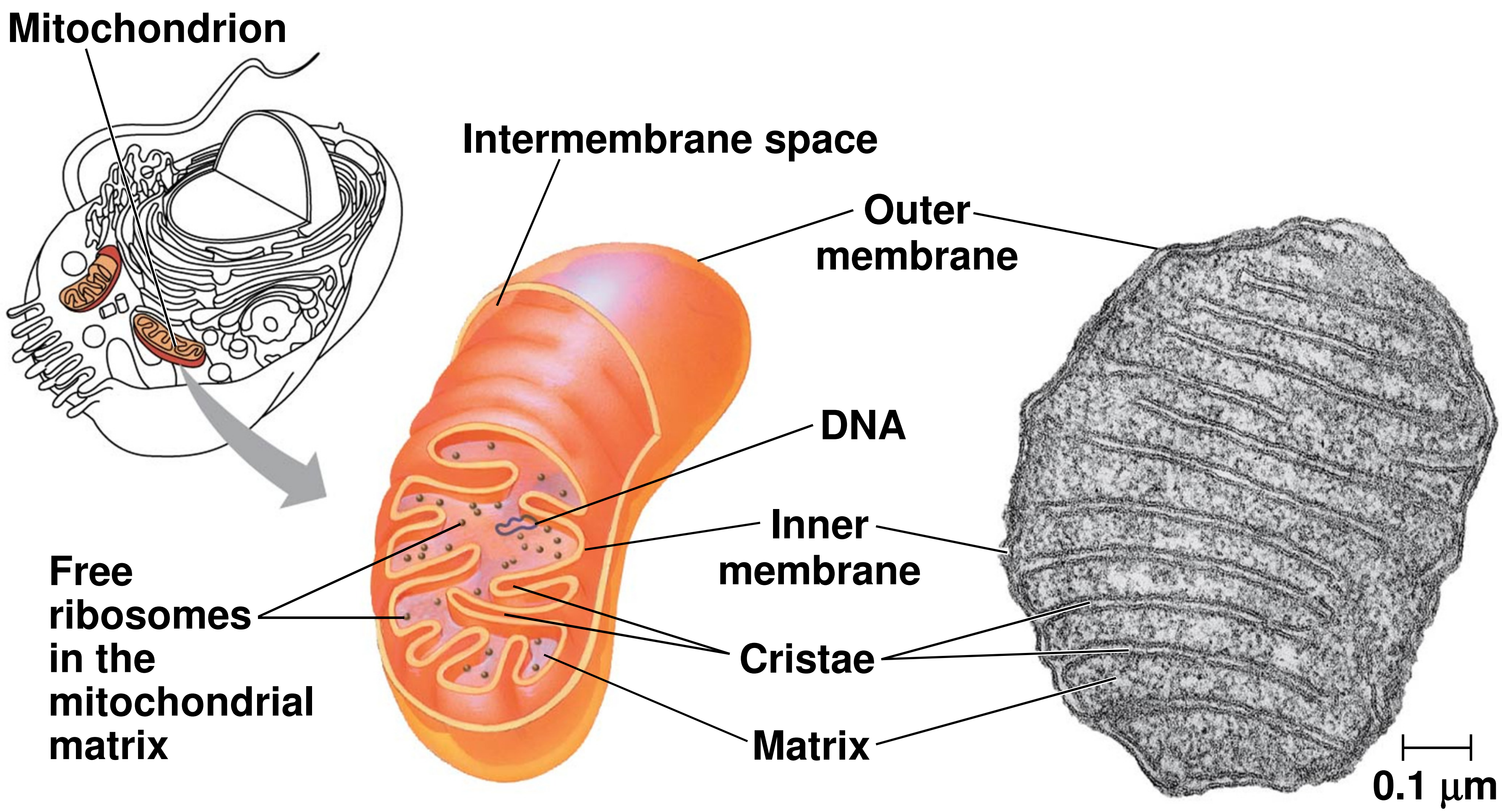


Endoplasmic reticulum
Nucleus
Nuclear envelope
Engulfing of oxygen-using nonphotosynthetic prokaryote, which becomes a mitochondrion
Mitochondrion
Ancestor of eukaryotic cells (host cell)
Nonphotosynthetic eukaryote
At least one cell
Engulfing of photosynthetic prokaryote
Chloroplast
Mitochondrion
Photosynthetic eukaryote

Mitochondria: Chemical Energy Conversion

- Mitochondria are in nearly all eukaryotic cells
- They have a smooth outer membrane and an inner membrane folded into **cristae**
- Cristae present a large surface area for enzymes that synthesize ATP
  - Structure fitting function!
- The inner membrane creates two compartments: intermembrane space and **mitochondrial matrix**

Figure 4.17

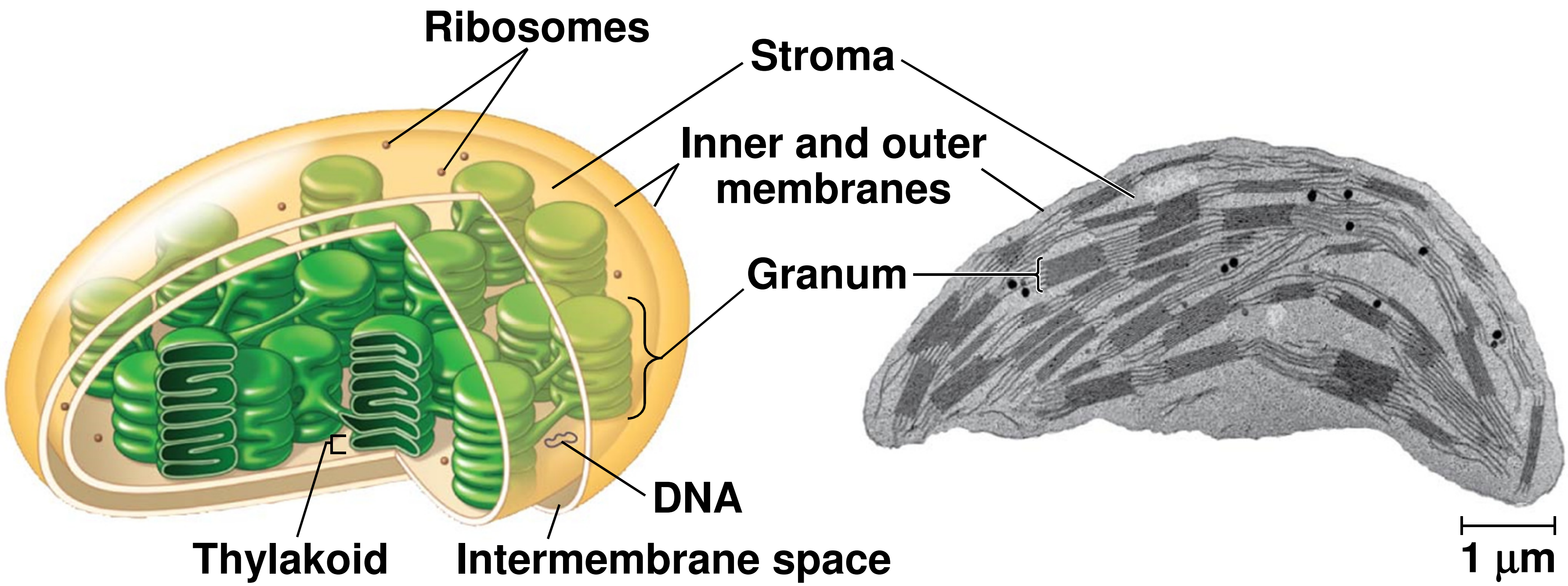

Mitochondrion
Intermembrane space
Outer membrane
DNA
Inner membrane
Free ribosomes in the mitochondrial matrix
Cristae
Matrix
0.1 µm

Chloroplasts: Capture of Light Energy

- Chloroplasts contain the green pigment chlorophyll, as well as enzymes and other molecules that function in photosynthesis
- Chloroplasts are found in leaves and other green organs of plants and in algae
- The chloroplast is one of a group of plant organelles called **plastids**

- Chloroplast structure includes
  - **Thylakoids**, membranous sacs, stacked to form a **granum**
  - **Stroma**, the internal fluid
    - Contains the chloroplast DNA, ribosomes, and many enzymes
- Membranes divide the chloroplast space into 3 compartments
  - Intermembrane space
  - Stroma
  - Thylakoid space
- Compartmental organization enables chloroplast to convert light energy to chemical energy during photosynthesis

Figure 4.18a



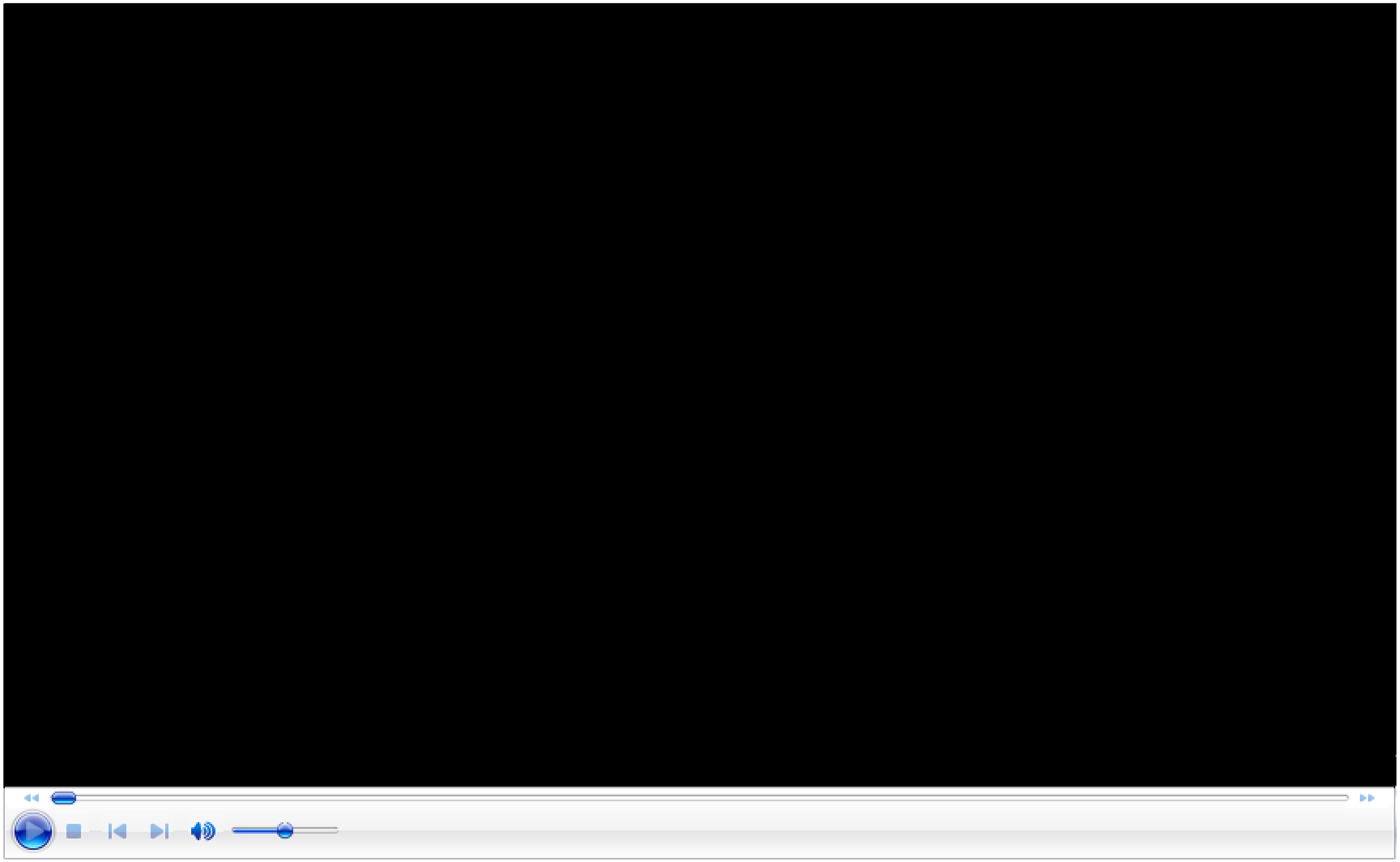
(a) Diagram and TEM of chloroplast

Peroxisomes: Oxidation

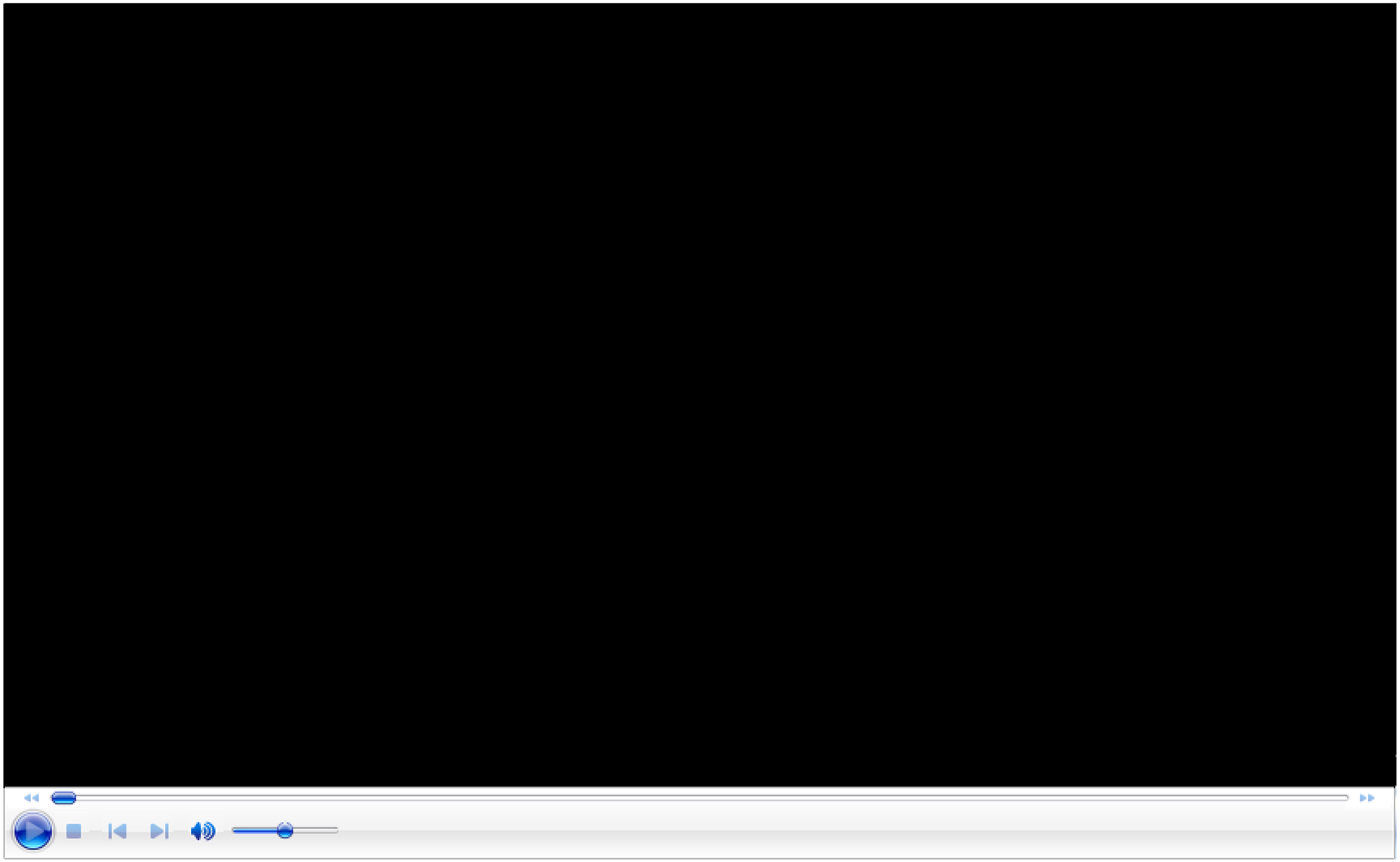
- **Peroxisomes** are specialized metabolic compartments bounded by a single membrane
- Peroxisomes contain enzymes that remove hydrogen atoms from certain molecules and transfer them to oxygen, producing hydrogen peroxide
- Peroxisomes perform reactions with many different functions
  - Detoxify alcohol and other harmful compounds

Concept 4.6: The cytoskeleton is a network of fibers that organizes structures and activities in the cell

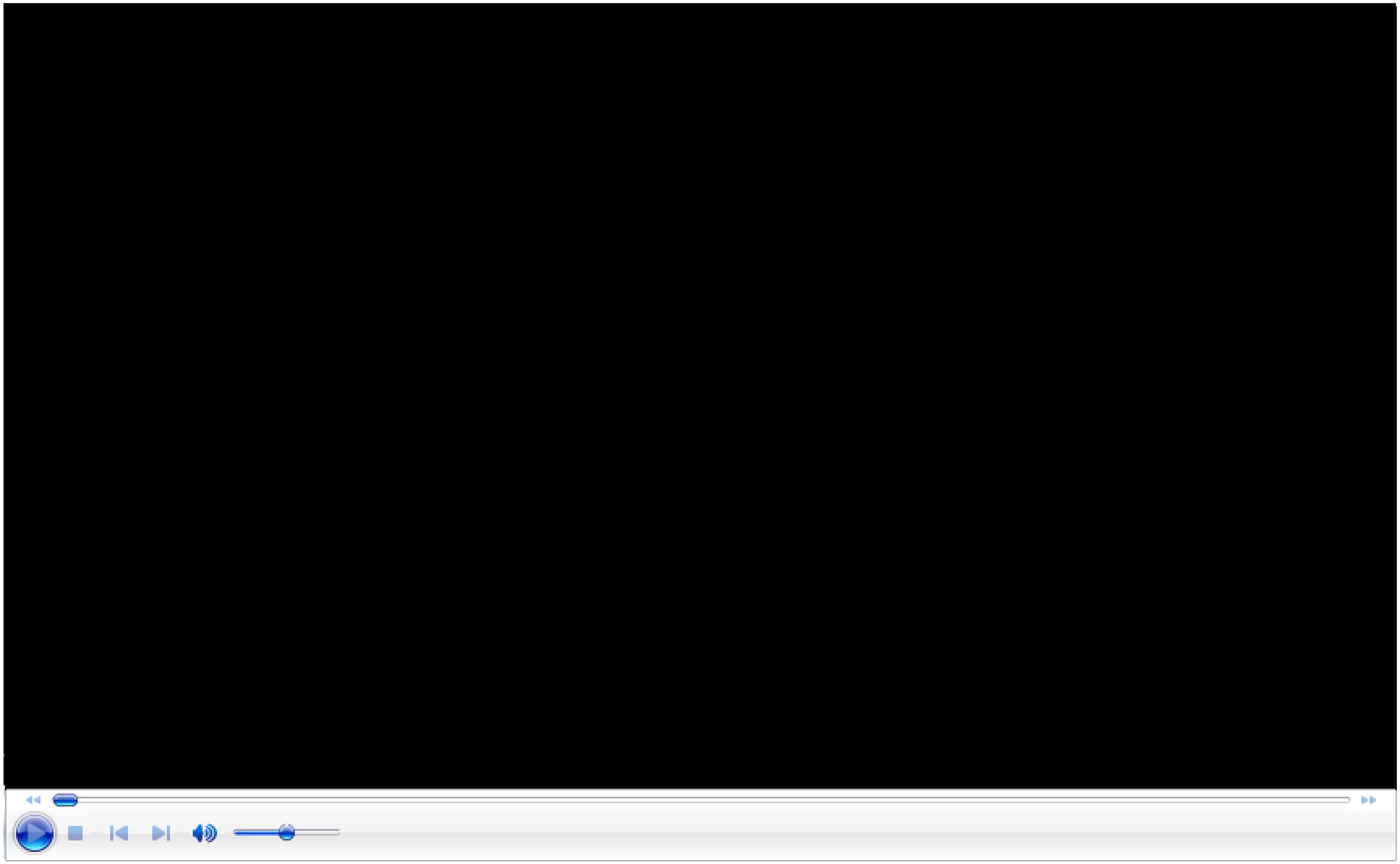
- The **cytoskeleton** is a network of fibers extending throughout the cytoplasm
- It organizes the cell's structures and activities, anchoring many organelles



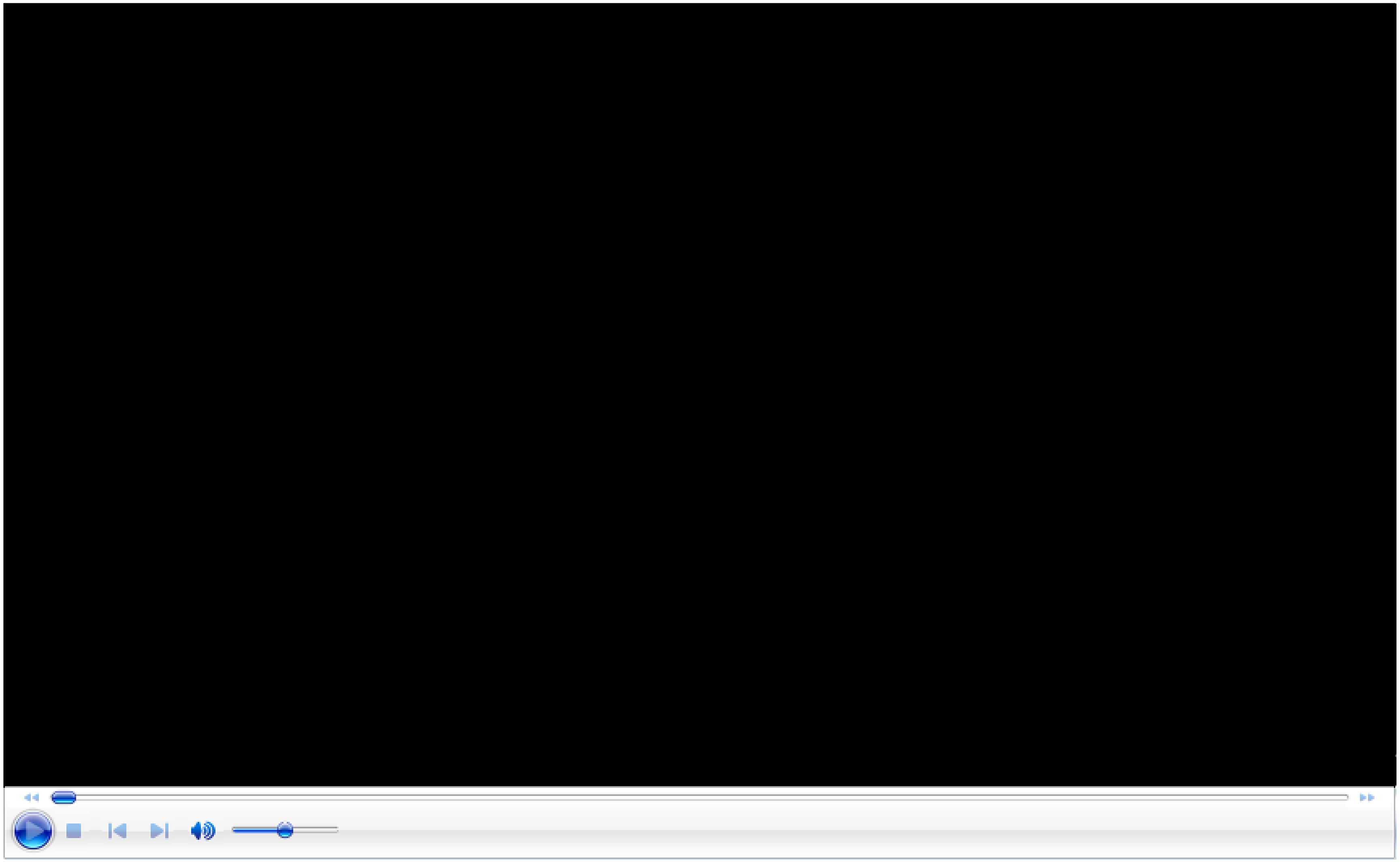
Video: Cytoskeleton in Neuron



Video: Microtubule Transport



Video: Organelle Movement

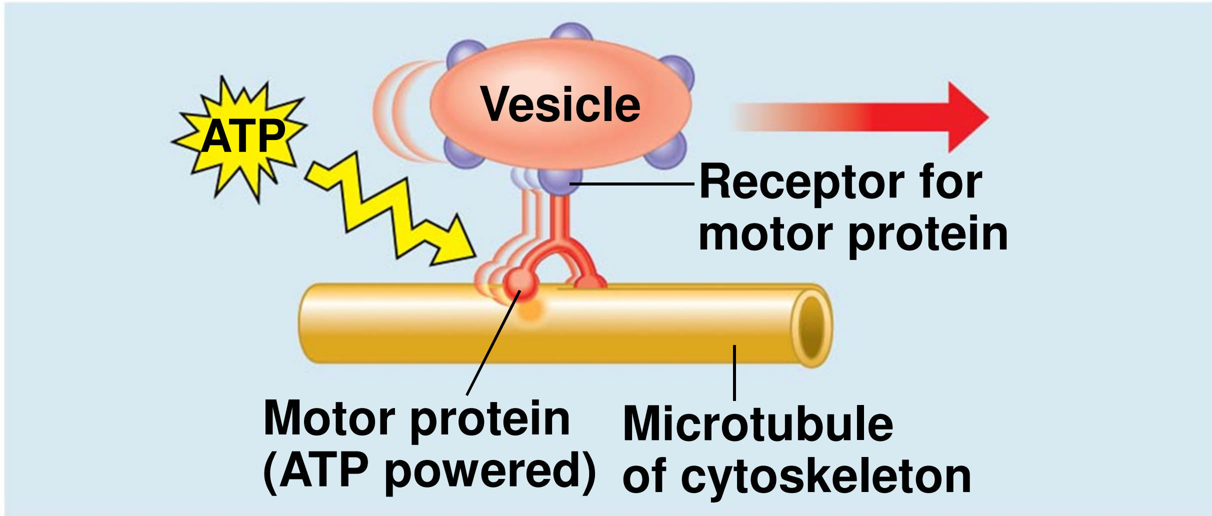


Video: Organelle Transport

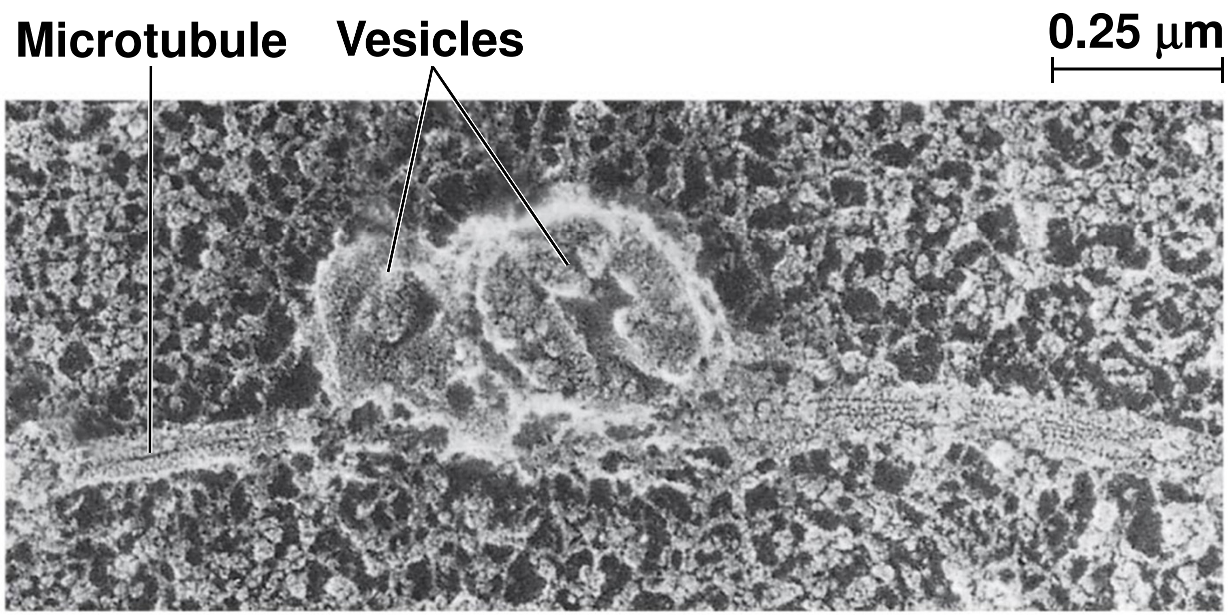
Roles of the Cytoskeleton: Support and Motility

- The cytoskeleton helps to support the cell and maintain its shape
  - Especially important for animal cell (lack cell walls)
- Provides anchorage
- It interacts with **motor proteins** to produce motility
- Inside the cell, vesicles and other organelles can “walk” along the tracks provided by the cytoskeleton

Figure 4.21



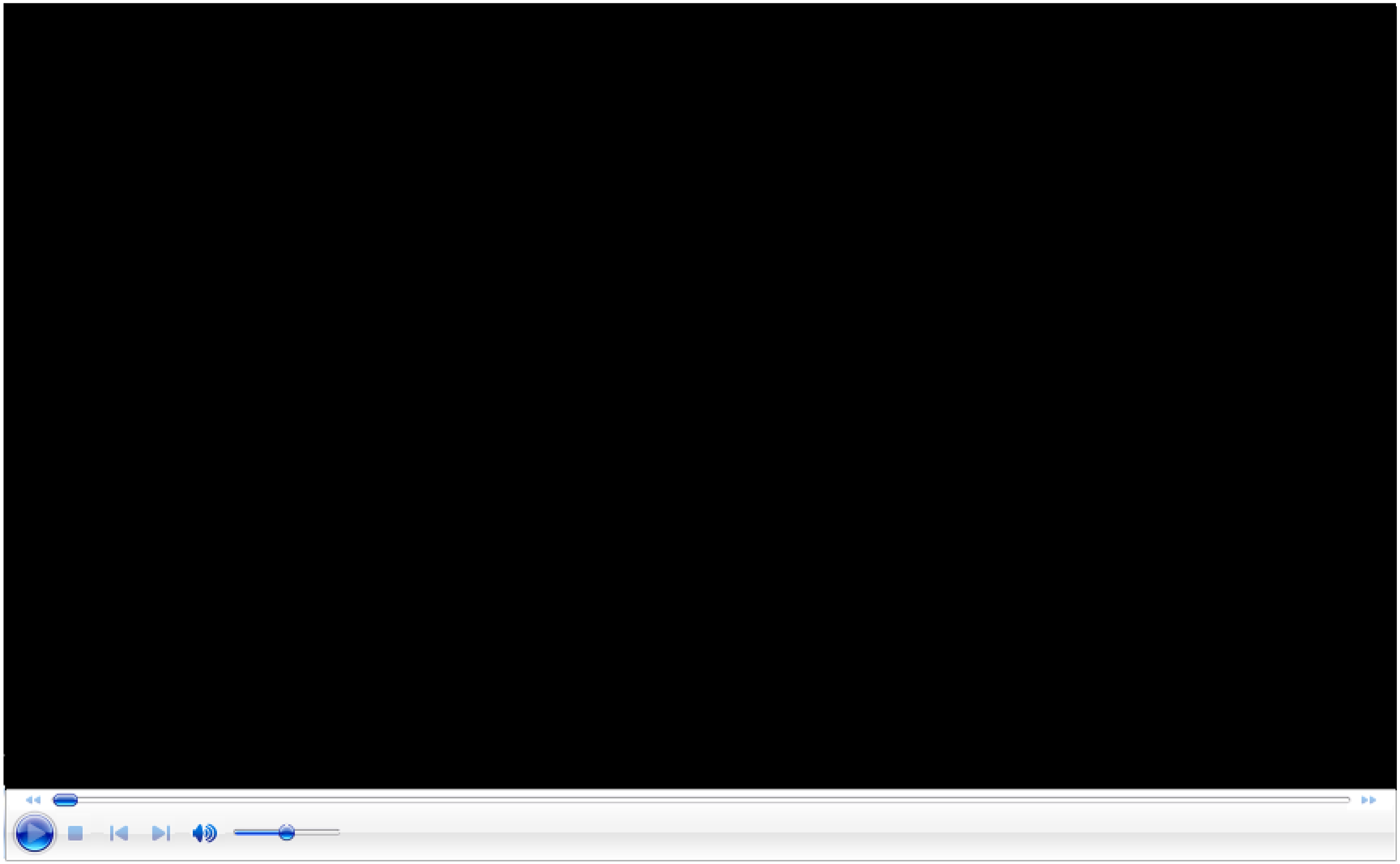
(a) Motor proteins "walk" vesicles along cytoskeletal fibers.



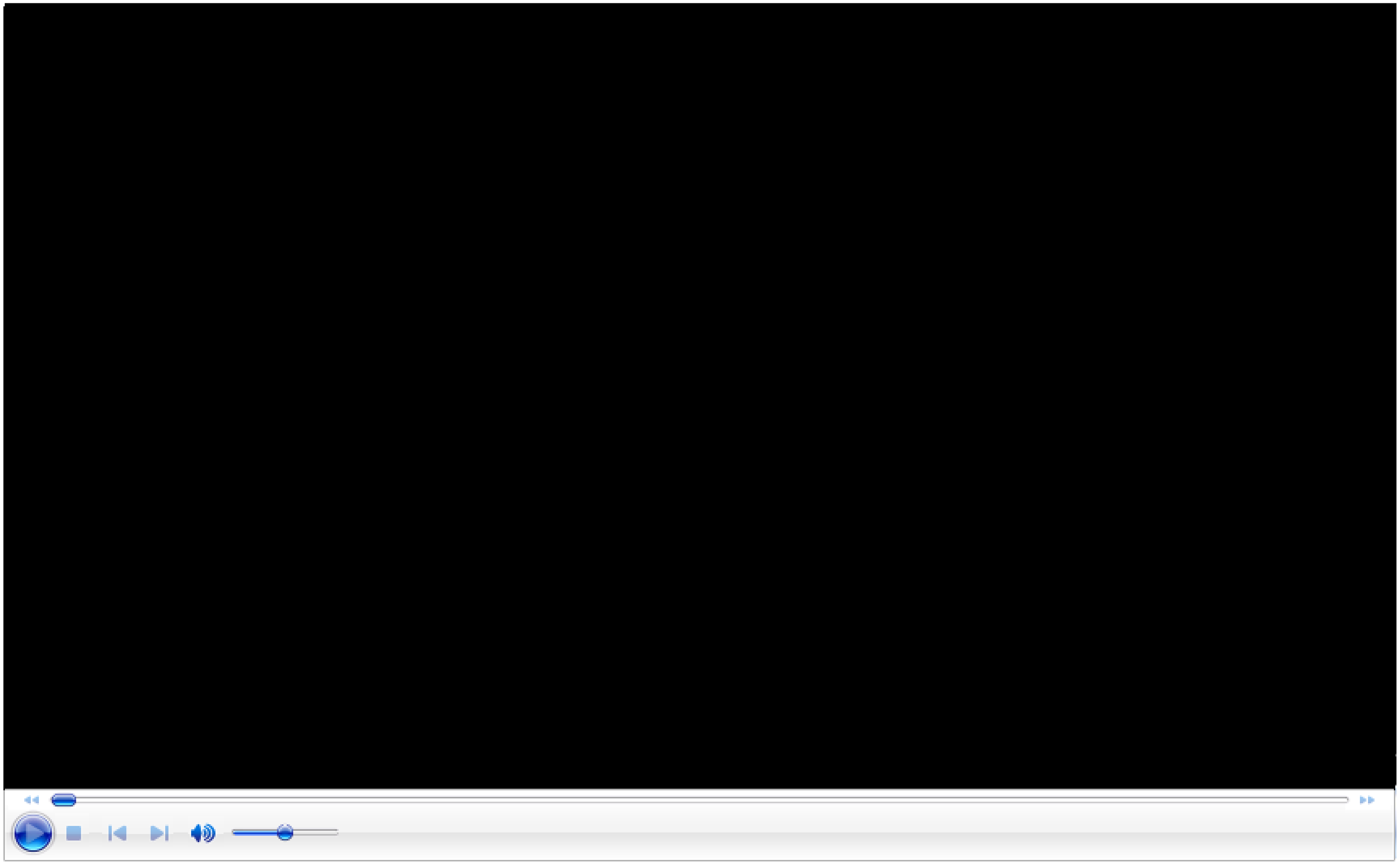
(b) SEM of a squid giant axon

Components of the Cytoskeleton

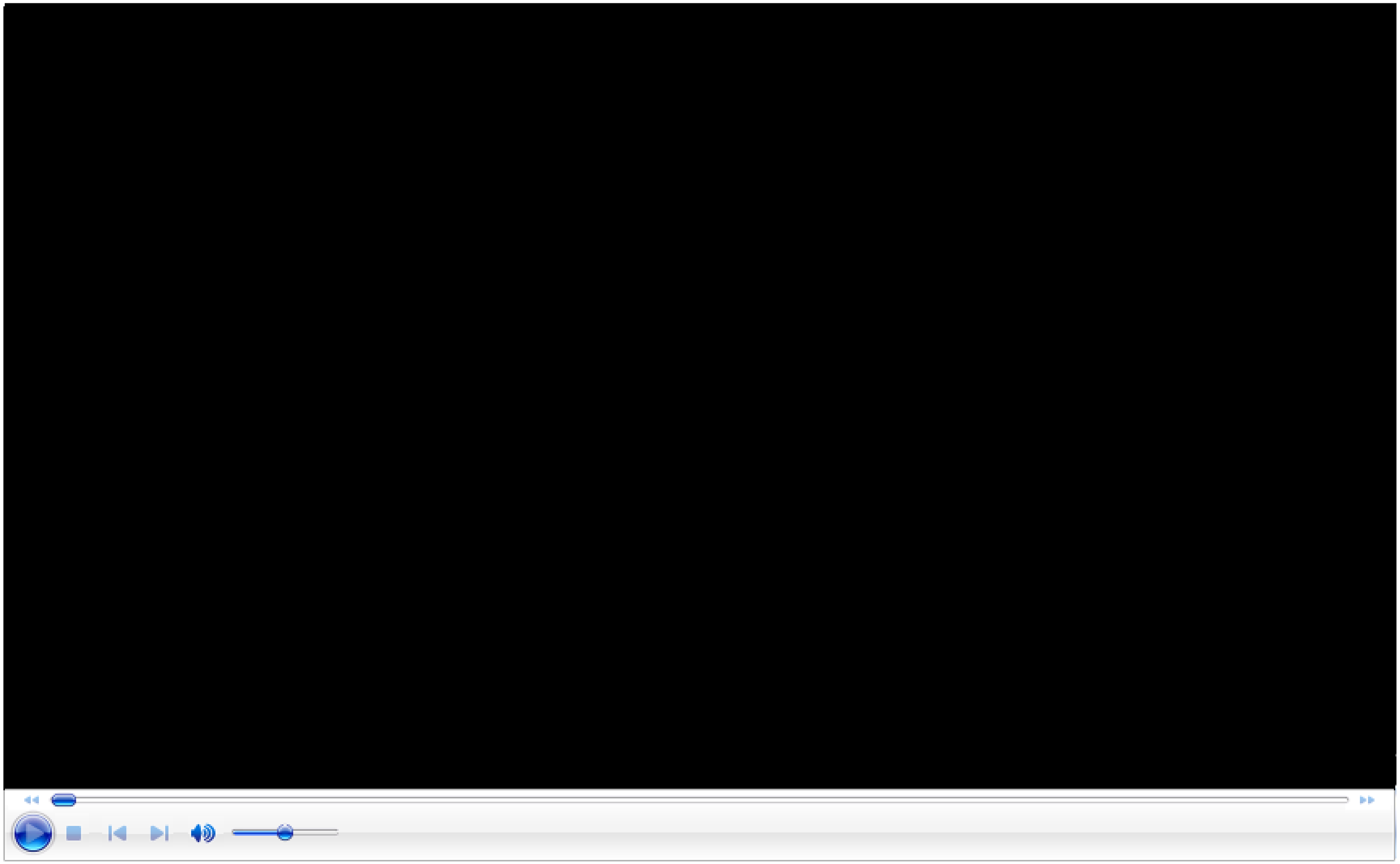
- Three main types of fibers make up the cytoskeleton
  - Microtubules are the thickest of the three components of the cytoskeleton
  - Microfilaments, also called actin filaments, are the thinnest components
  - Intermediate filaments are fibers with diameters in a middle range



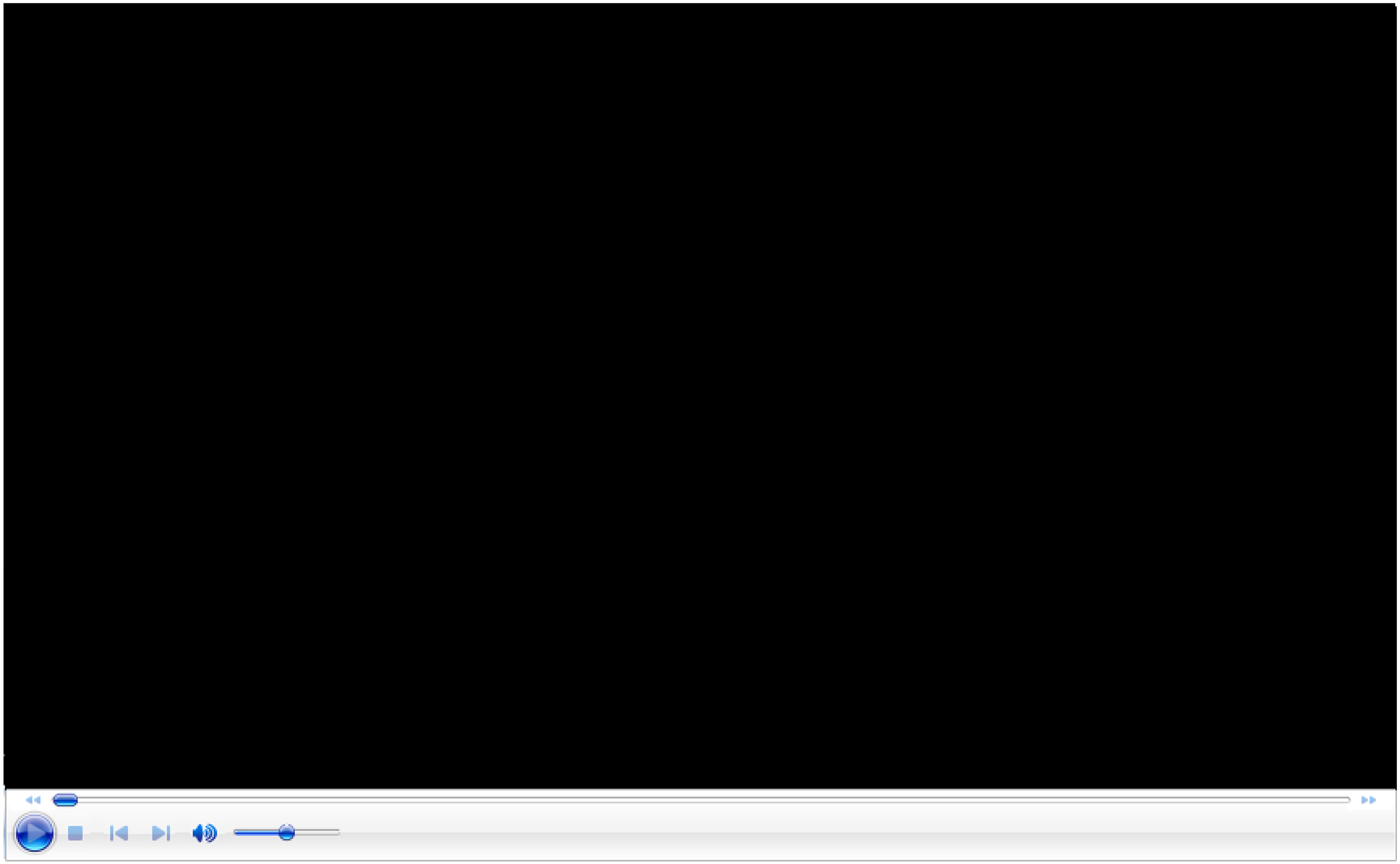
Video: Actin Cytoskeleton



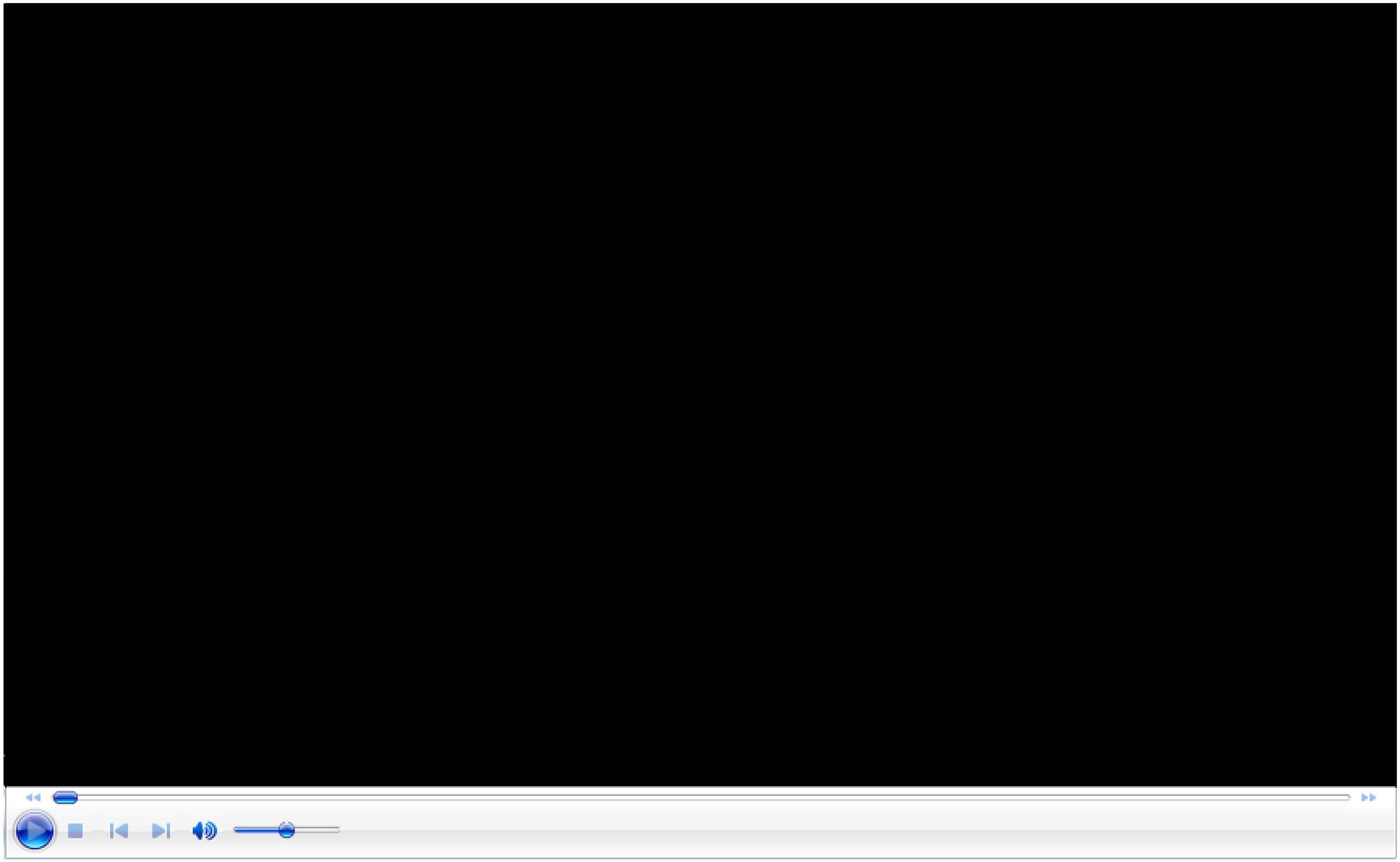
Video: Actin in Crawling Cell



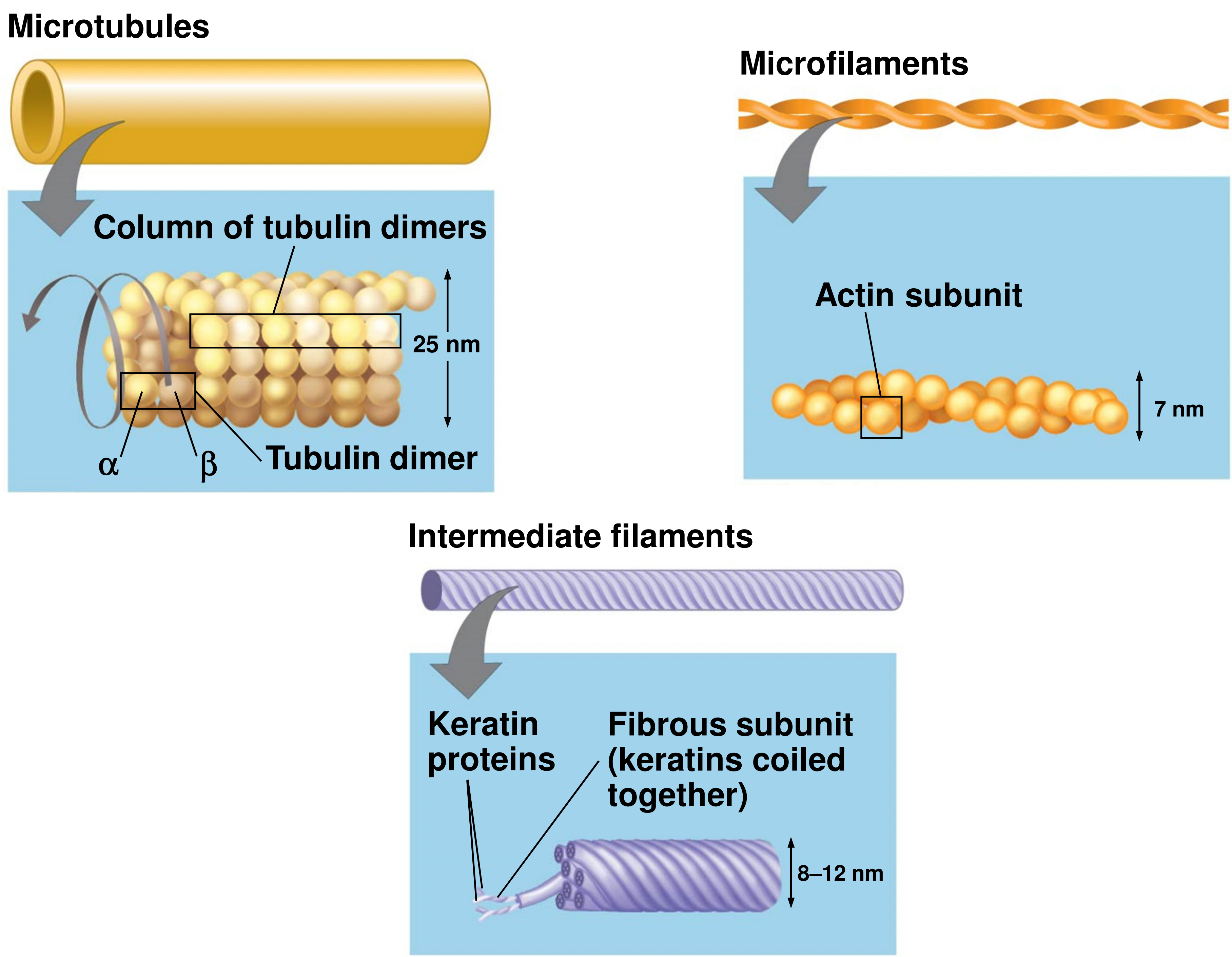
Video: Actin in Neuron



Video: Microtubule Movement



Video: Microtubules

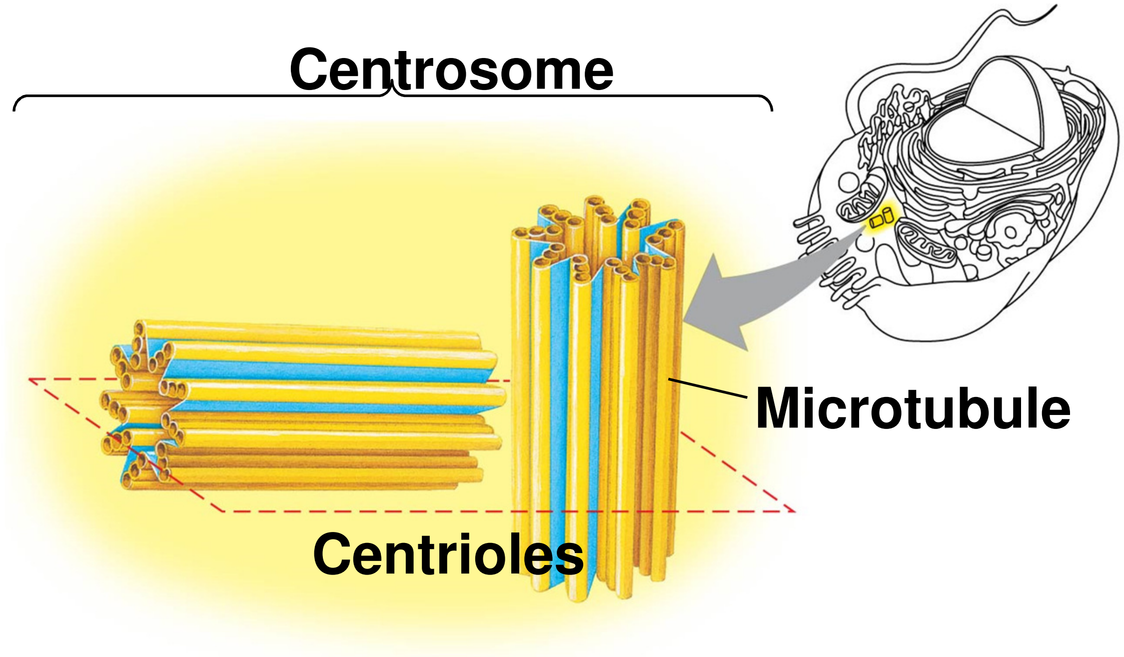

Microtubules
Column of tubulin dimers
25 nm
α
β
Tubulin dimer
Microfilaments
Actin subunit
7 nm
Intermediate filaments
Keratin proteins
Fibrous subunit (keratins coiled together)
8–12 nm

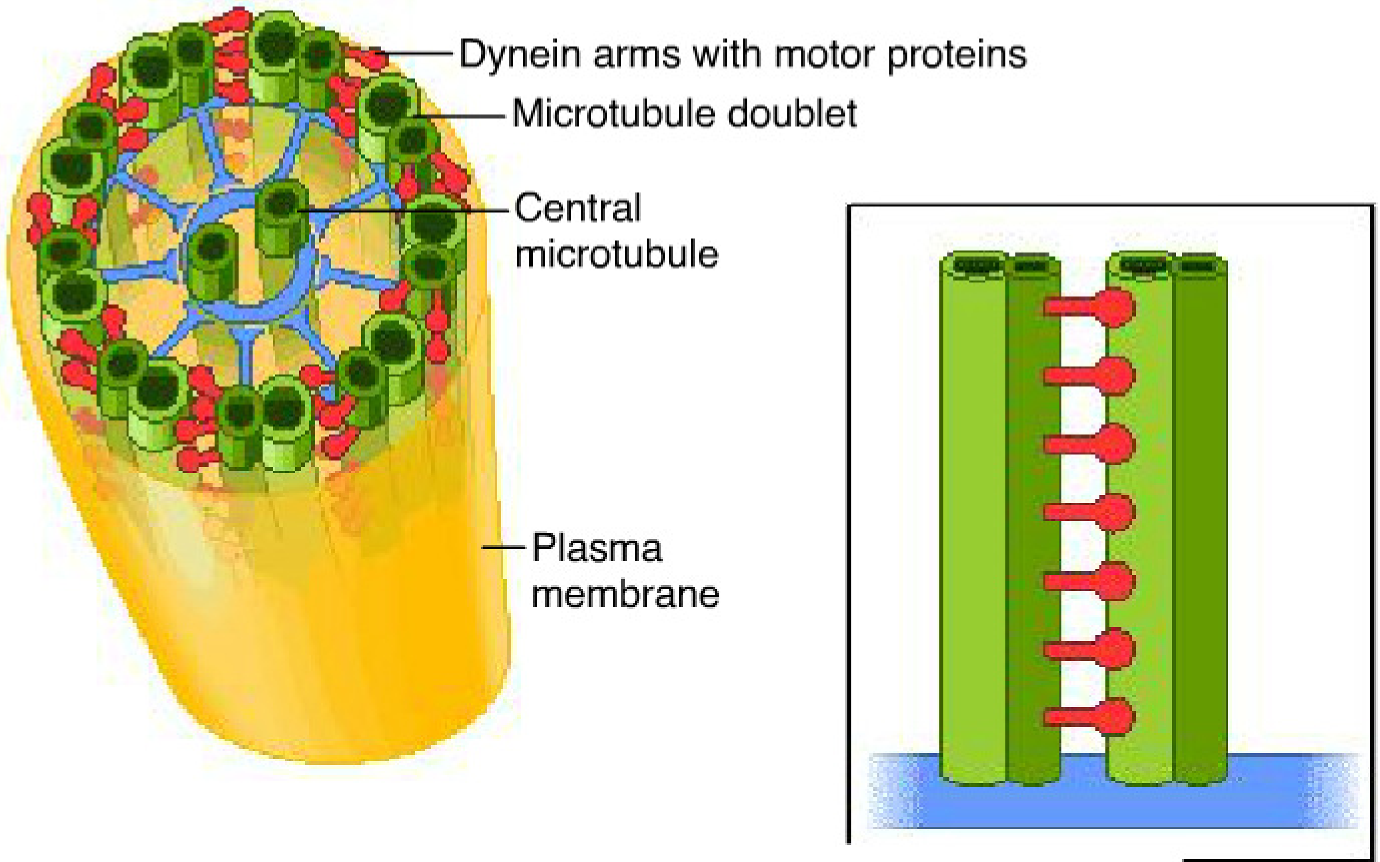
Microtubules

- **Microtubules** are hollow rods constructed from globular protein dimers called tubulin
- Functions of microtubules
  - Shape and support the cell
  - Guide movement of organelles
  - Separate chromosomes during cell division

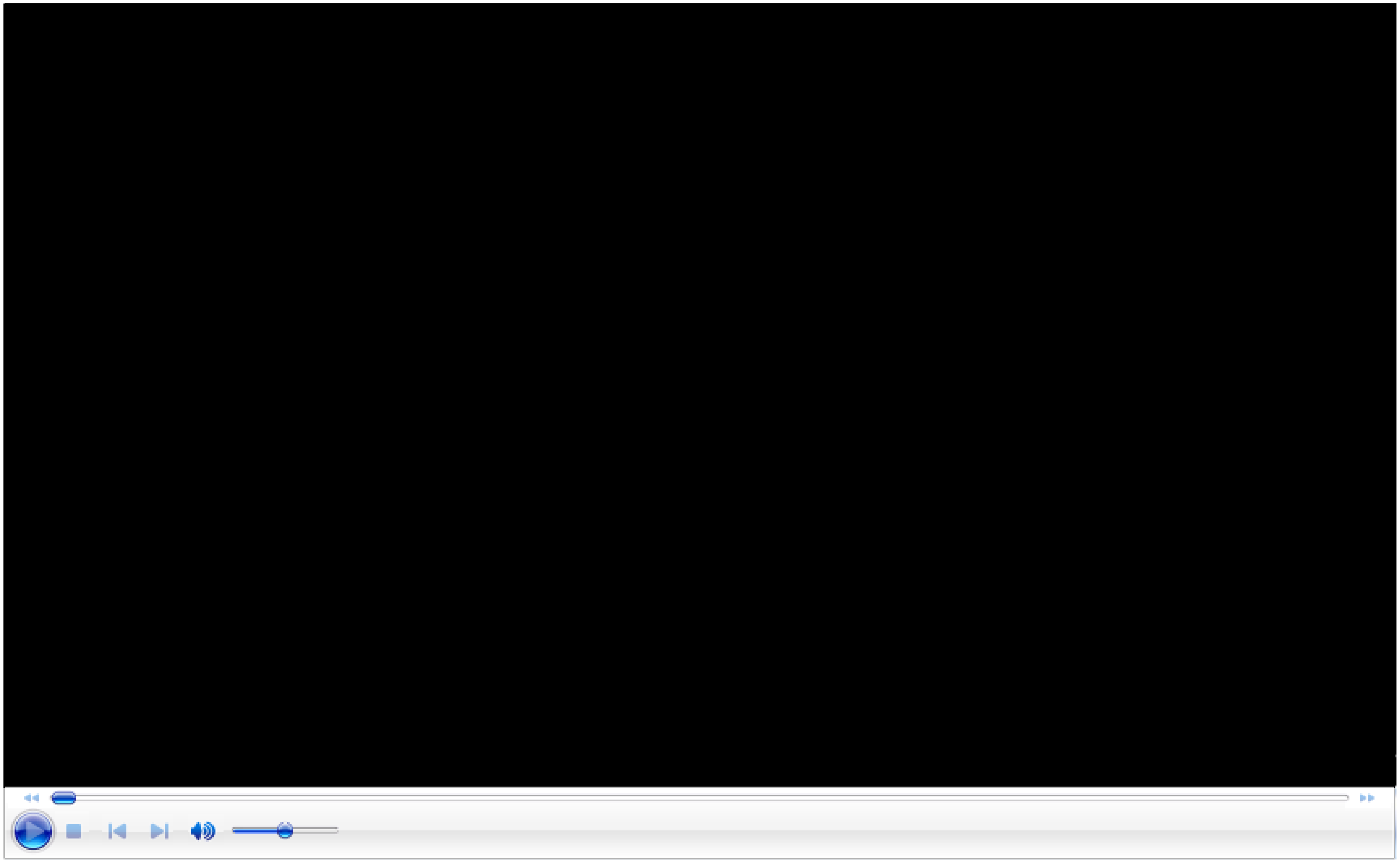
Centrosomes and Centrioles

- In animal cells, microtubules grow out from a **centrosome** near the nucleus
- The centrosome is a "microtubule-organizing center"
- The centrosome has a pair of **centrioles**, each with nine triplets of microtubules arranged in a ring

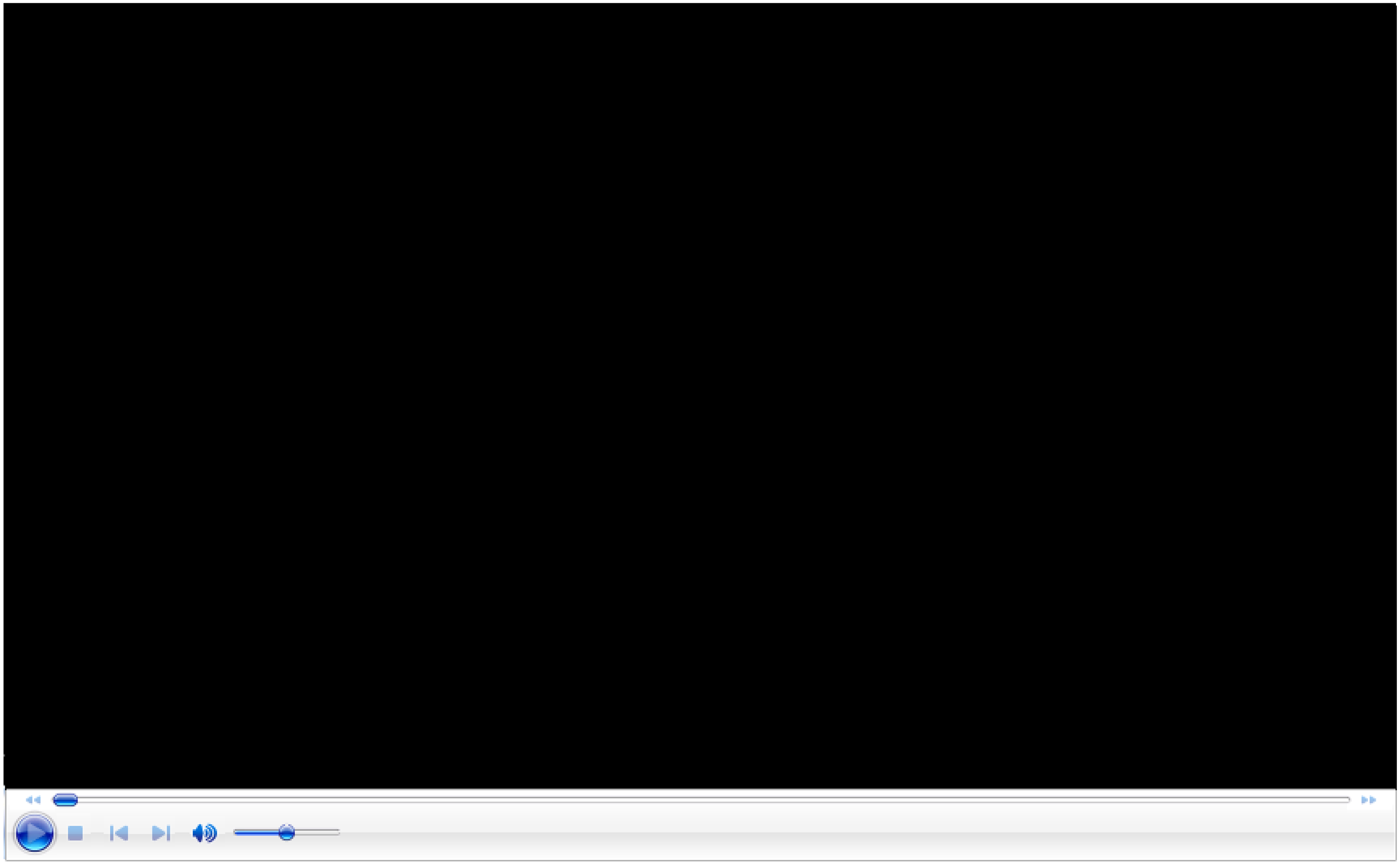




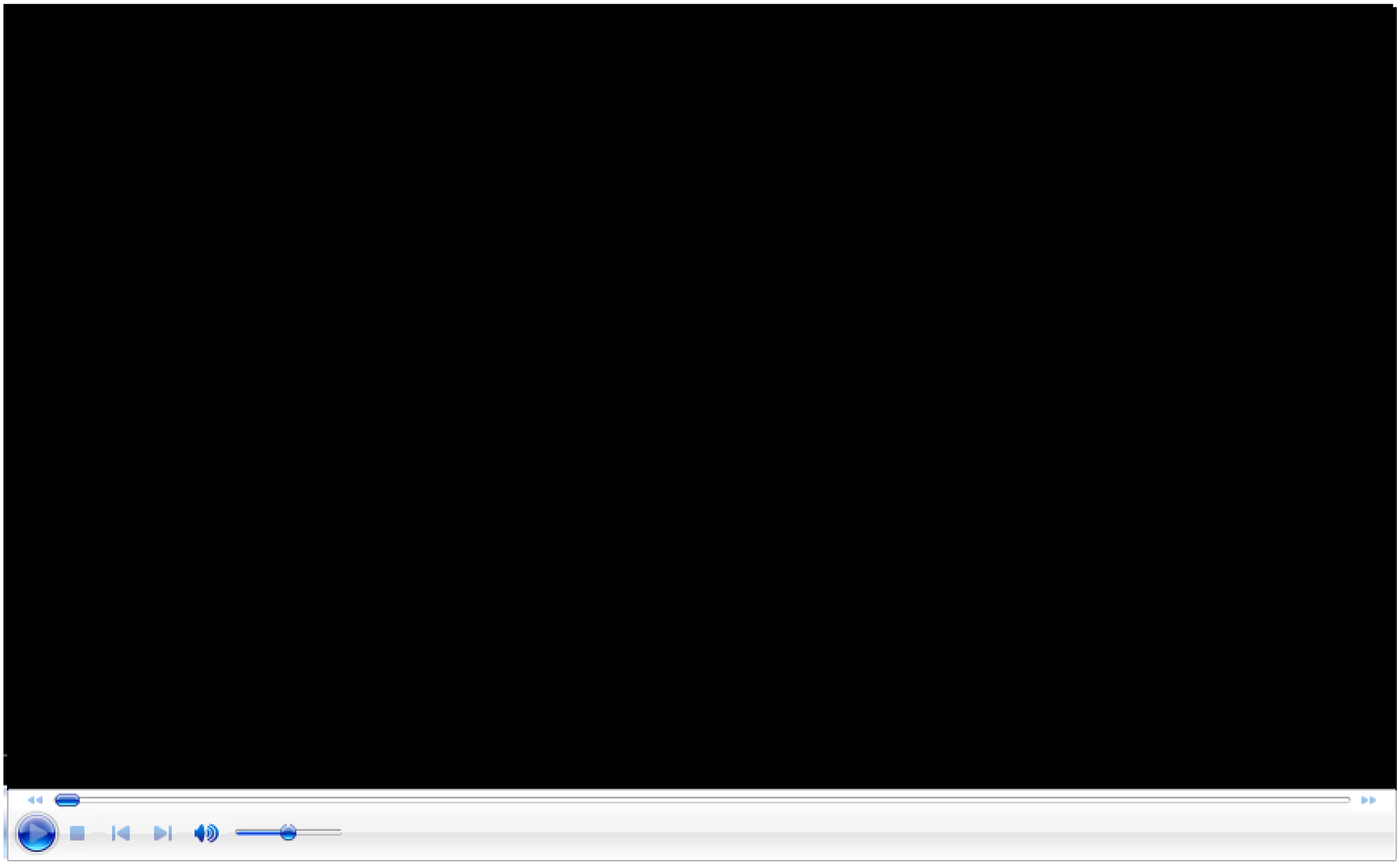
Animation: Cilia Flagella
Right click slide / Select play



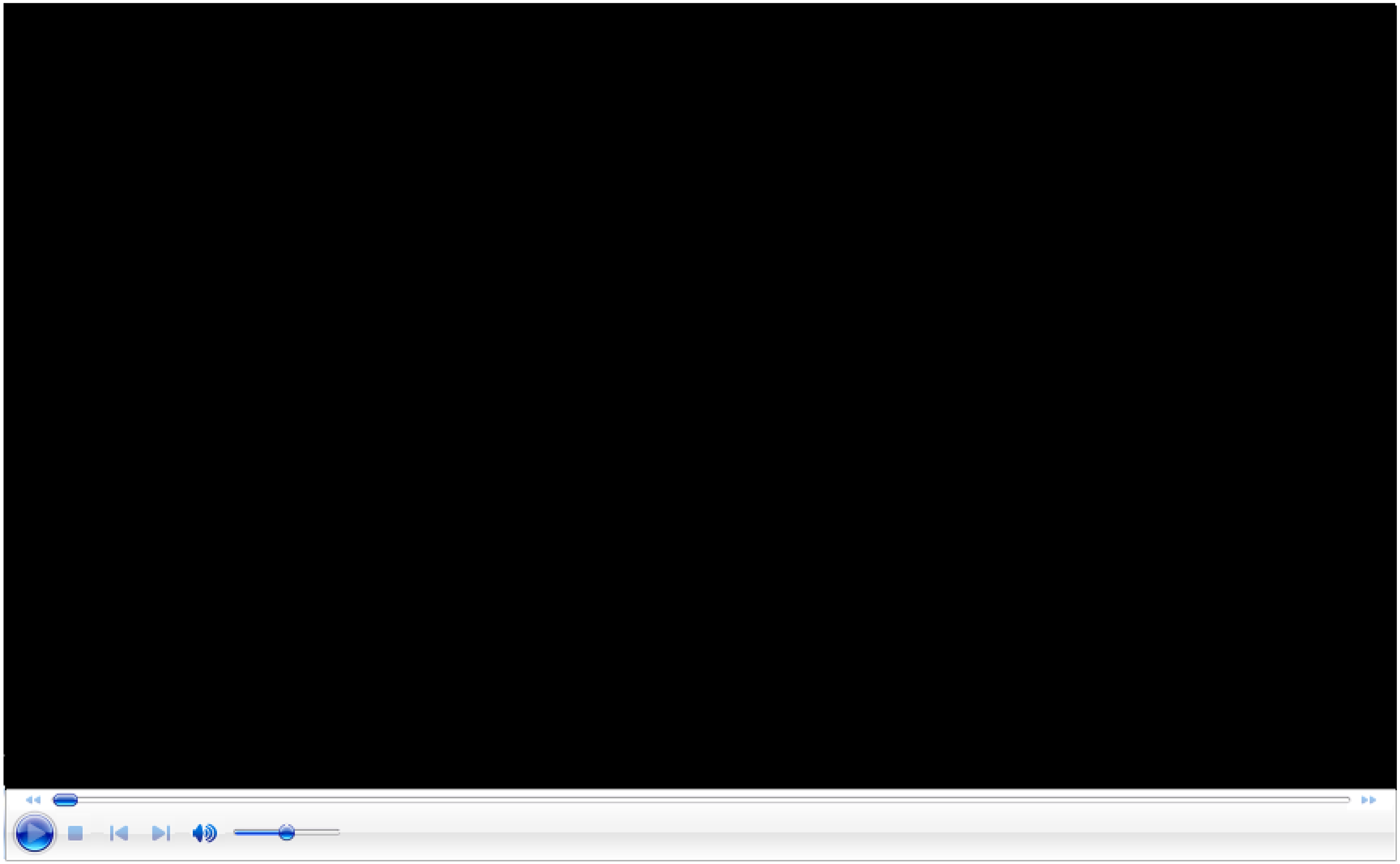
Video: Ciliary Motion



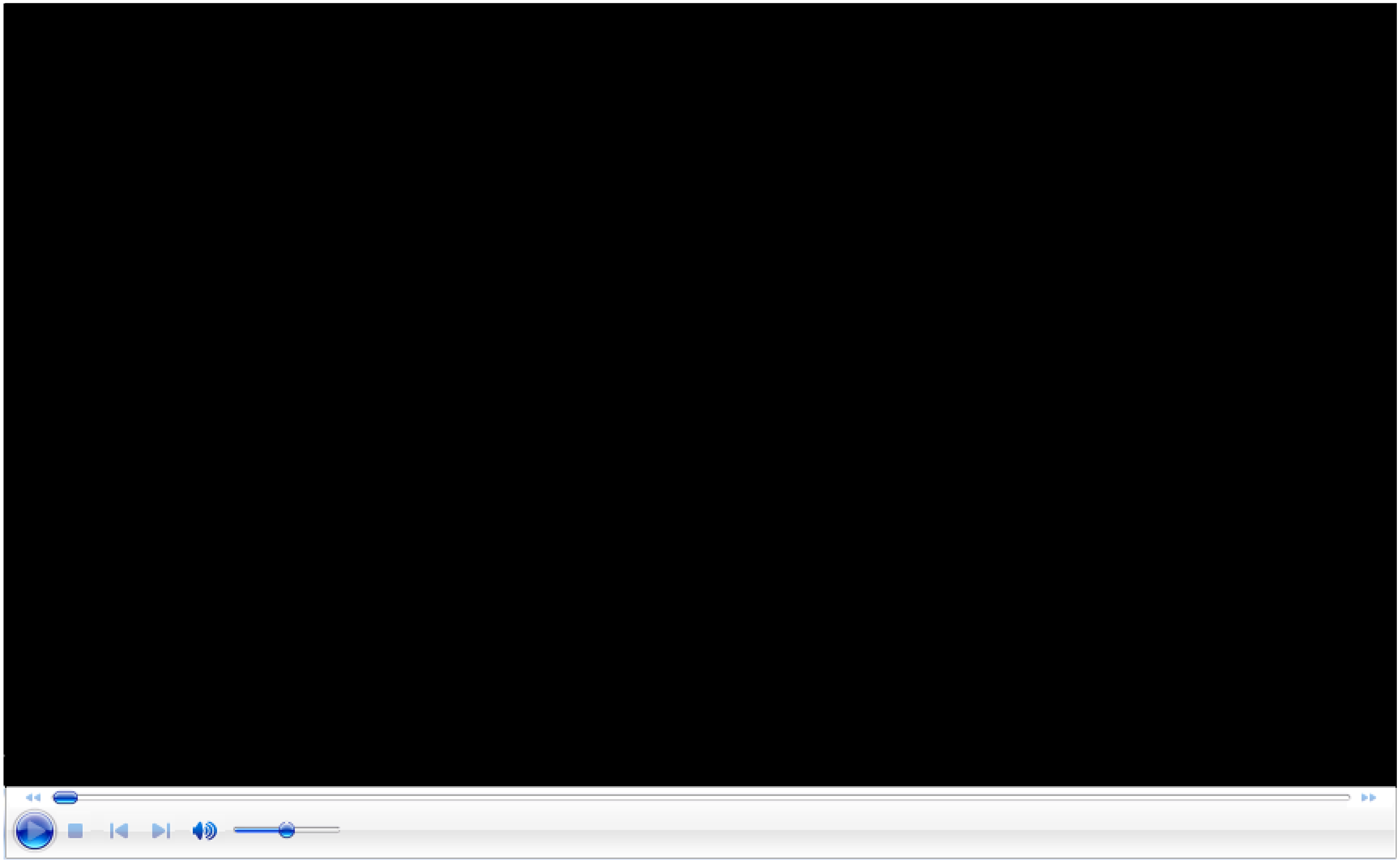
Video: Flagella in Sperm



Video: Flagellum Microtubule



Video: Sperm Flagellum



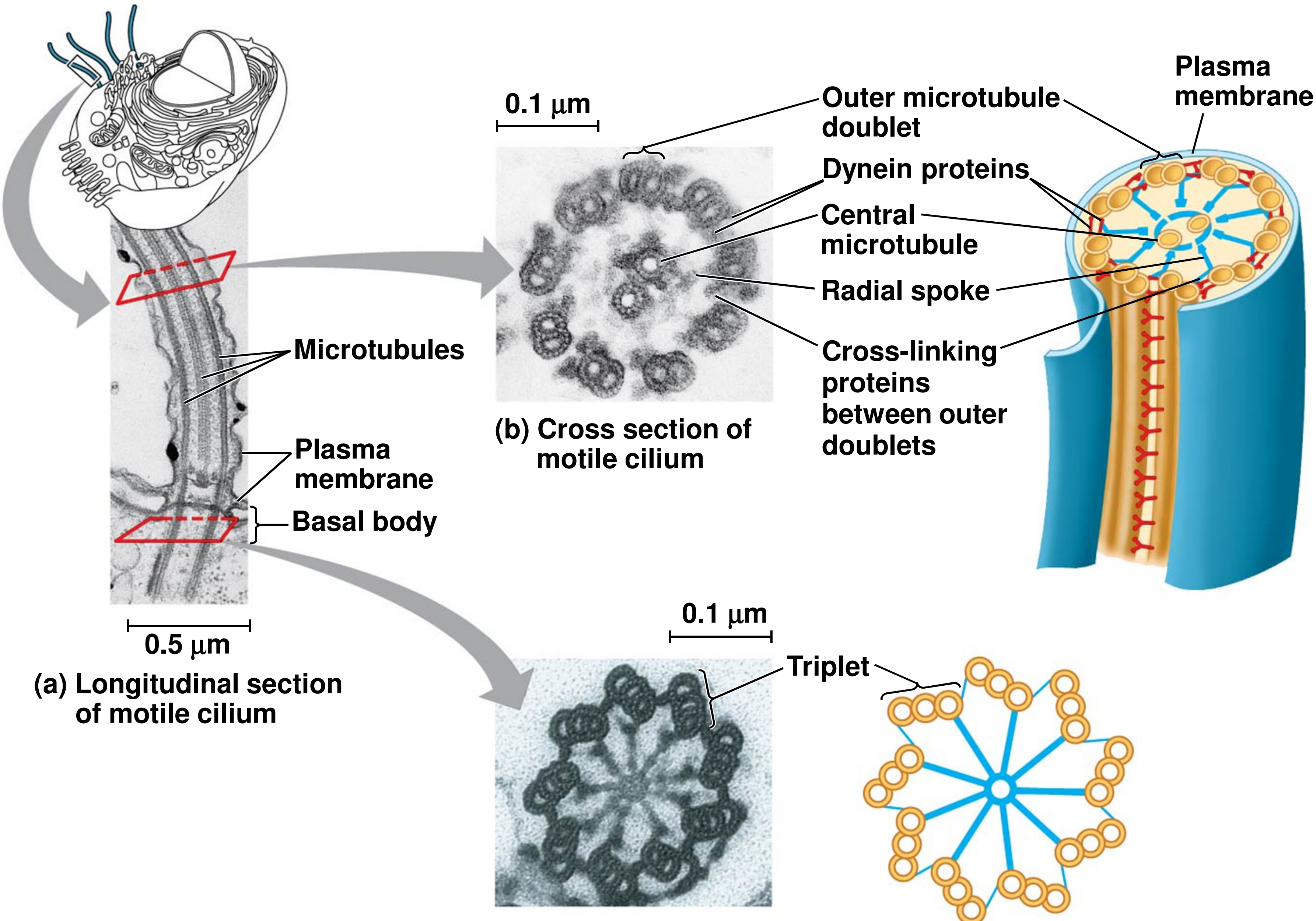
Video: *Paramecium* Cilia

Cilia and Flagella

- Microtubules control the beating of **cilia** and **flagella**, microtubule-containing extensions projecting from some cells
- Propel cells through water
- Can move fluid over the surface of a tissue
- Flagella are limited to one or a few per cell, while cilia occur in large numbers on cell surfaces
- Cilia and flagella also differ in their beating patterns

- Cilia and flagella share a common structure
  - A core of microtubules sheathed by the plasma membrane
  - A **basal body** that anchors the cilium or flagellum
  - A motor protein called **dynein**, which drives the bending movements of a cilium or flagellum

Figure 4.23



(a) Longitudinal section of motile cilium

(b) Cross section of motile cilium

(c) Cross section of basal body

- How dynein “walking” moves flagella and cilia
  - Dynein arms alternately grab, move, and release the outer microtubules
  - The outer doublets and central microtubules are held together by flexible cross-linking proteins
  - Movements of the doublet arms cause the cilium or flagellum to bend

Microfilaments (Actin Filaments)

- **Microfilaments** are thin solid rods, built from molecules of globular **actin** subunits
- The structural role of microfilaments is to bear tension, resisting pulling forces within the cell
- Bundles of microfilaments make up the core of microvilli of intestinal cells
  - Increase surface area

- Microfilaments that function in cellular motility interact with the motor protein **myosin**
- For example, actin and myosin interact to cause muscle contraction, amoeboid movement of white blood cells, and cytoplasmic streaming in plant cells

Intermediate Filaments

- **Intermediate filaments** are larger than microfilaments but smaller than microtubules
- They support cell shape and fix organelles in place
- Intermediate filaments are more permanent cytoskeleton elements than the other two classes

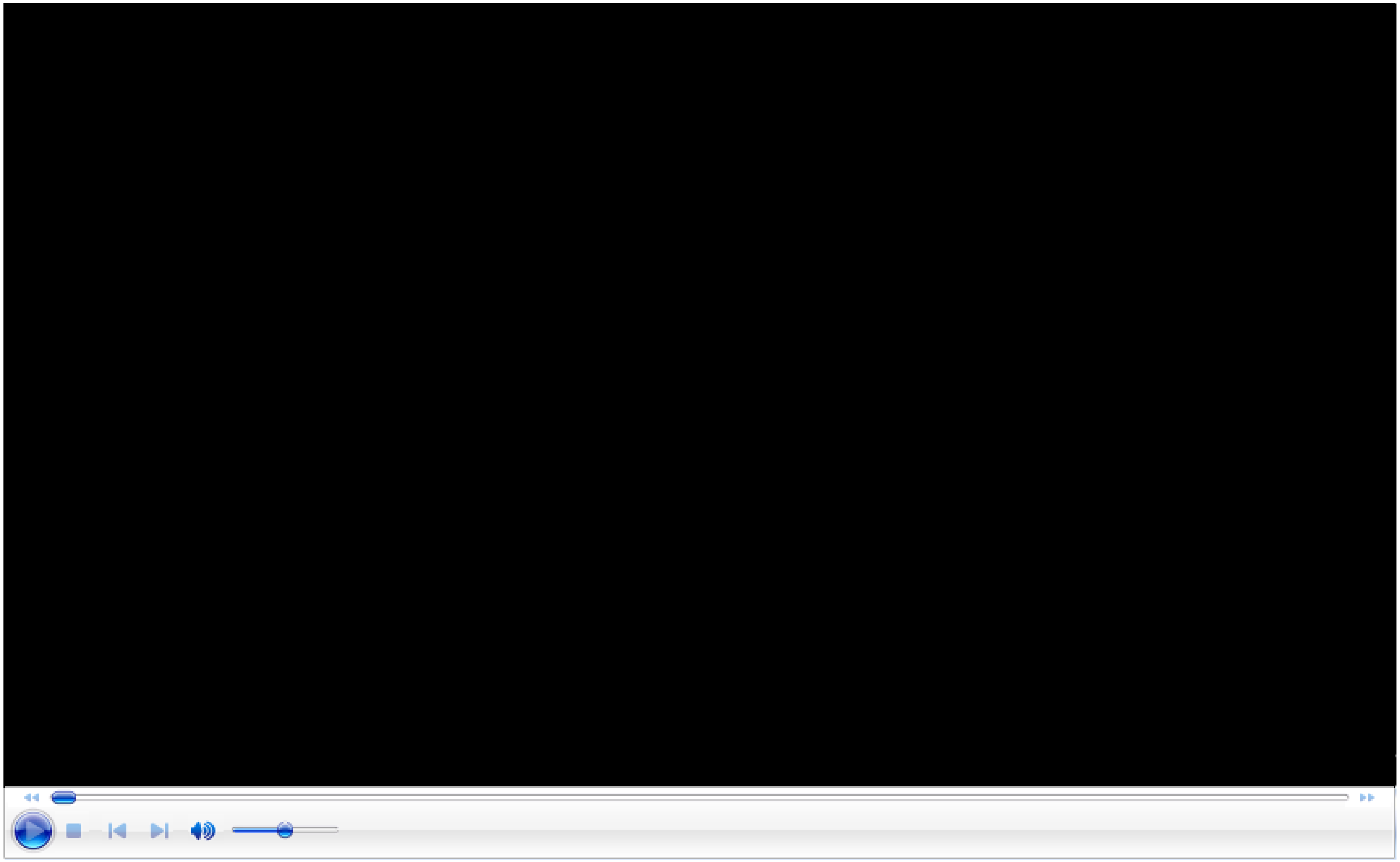
Concept 4.7: Extracellular components and connections between cells help coordinate cellular activities

- Most cells synthesize and secrete materials that are external to the plasma membrane
- These extracellular materials are involved in many cellular functions
  - Coordinate cell activities

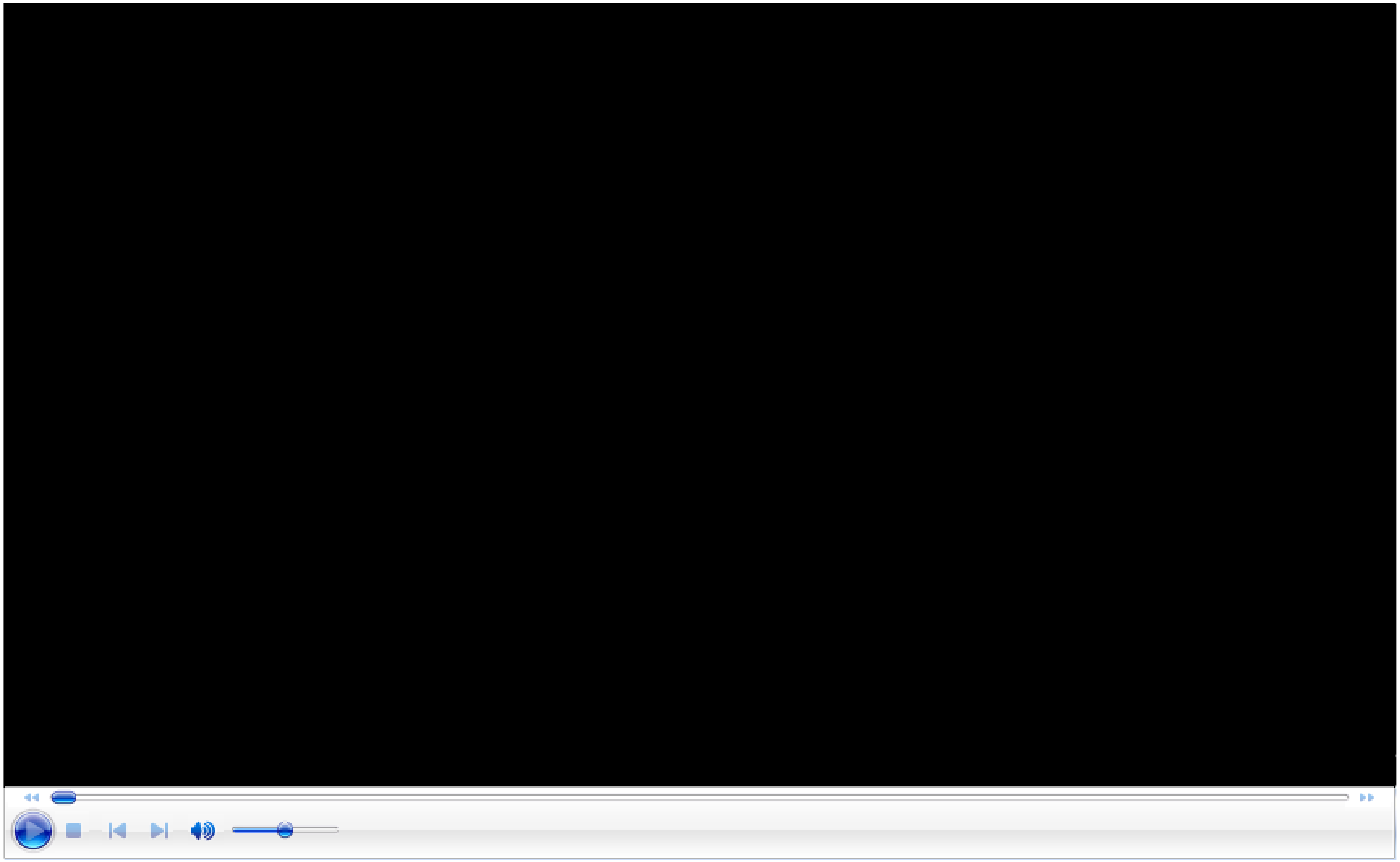
Cell Walls of Plants

- The **cell wall** is an extracellular structure that distinguishes plant cells from animal cells
- Prokaryotes, fungi, and some protists also have cell walls
- Functions:
  - Protects the plant cell
  - Maintains its shape
  - Prevents excessive uptake of water
  - Holds plant up against force of gravity
- Plant cell walls are made of cellulose fibers embedded in other polysaccharides and protein

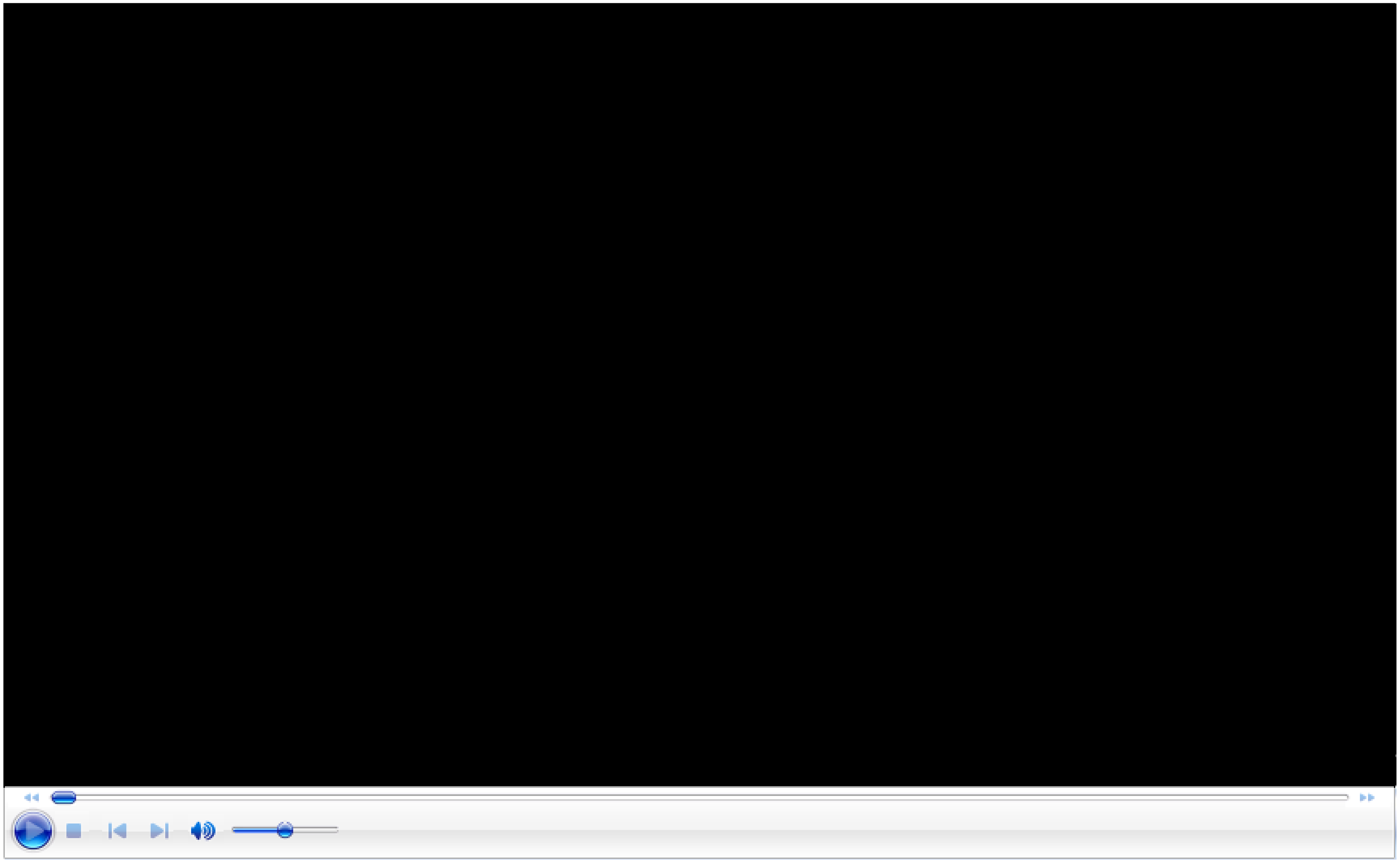
- Plant cell walls may have multiple layers
  - **Primary cell wall**: relatively thin and flexible
  - **Middle lamella**: thin layer between primary walls of adjacent cells
    - Pectin glues adjacent cells together
  - **Secondary cell wall** (in some cells): added between the plasma membrane and the primary cell wall
    - Has strong and durable matrix that provides protection and support
- Plasmodesmata are channels between adjacent plant cells



Video: Collagen Model

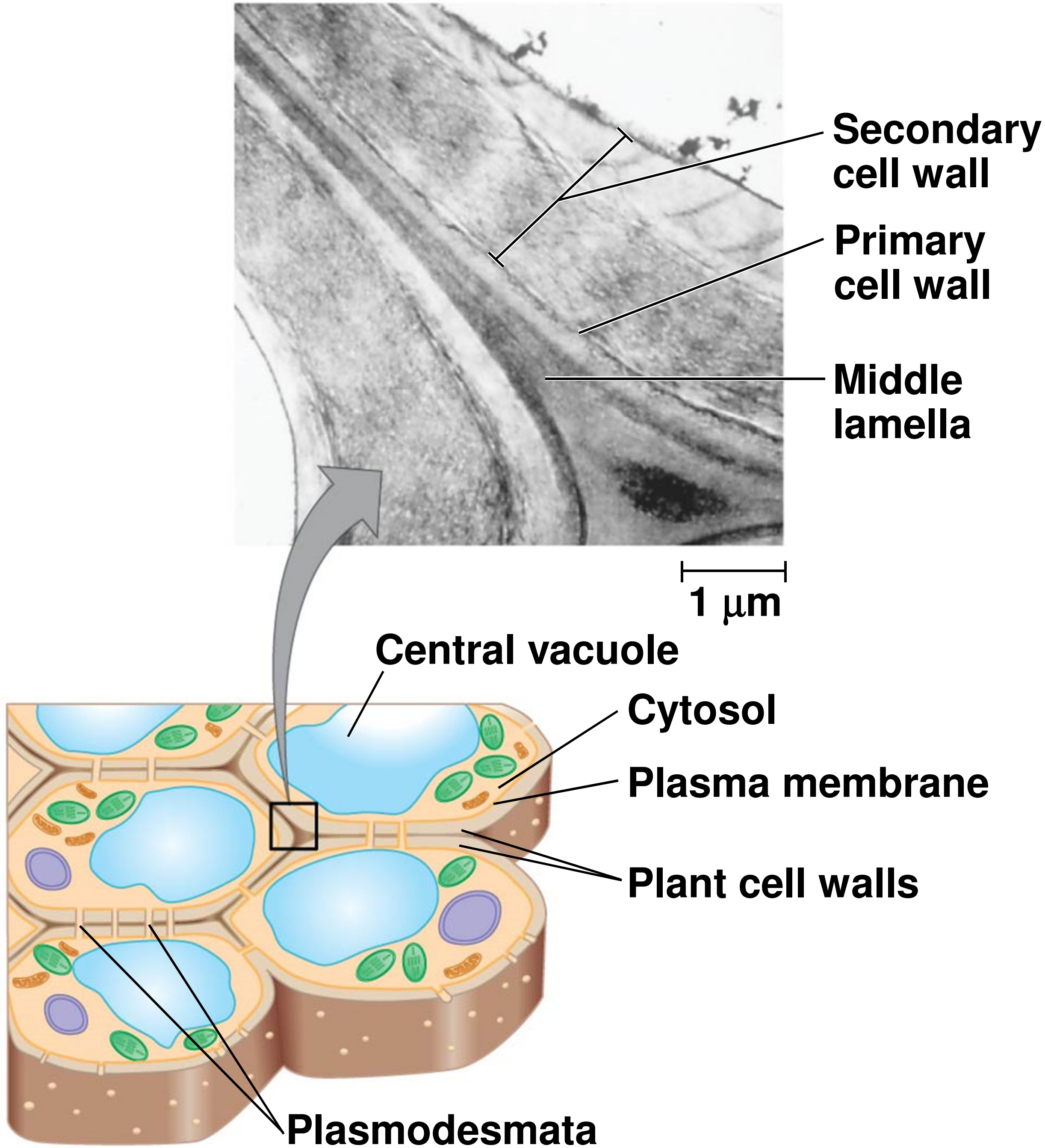


Video: Extracellular Matrix



Video: Fibronectin

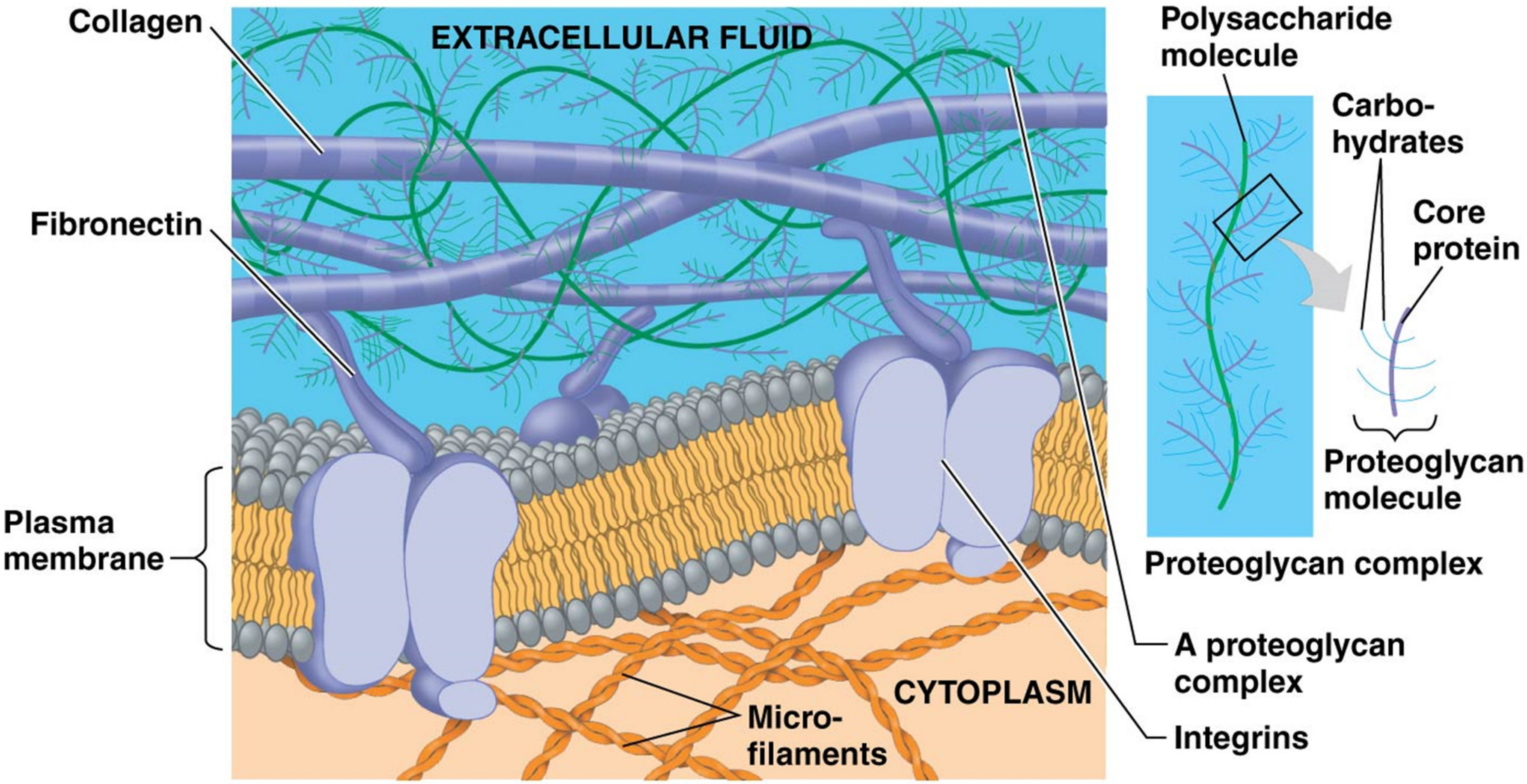
Figure 4.25


Secondary cell wall
Primary cell wall
Middle lamella
1 µm
Central vacuole
Cytosol
Plasma membrane
Plant cell walls
Plasmodesmata

The Extracellular Matrix (ECM) of Animal Cells

- Animal cells lack cell walls but are covered by an elaborate **extracellular matrix (ECM)**
- The ECM is made up of glycoproteins such as **collagen**, **proteoglycans**, and **fibronectin**
- ECM proteins bind to receptor proteins in the plasma membrane called **integrins**
  - In a position to transmit signals
- ECM can regulate a cell's behavior by communicating with a cell through integrins

Figure 4.26



Collagen
EXTRACELLULAR FLUID
Fibronectin
Plasma membrane
Micro-filaments
CYTOPLASM
Polysaccharide molecule
Carbo-hydrates
Core protein
Proteoglycan molecule
Proteoglycan complex
A proteoglycan complex
Integrins

Cell Junctions

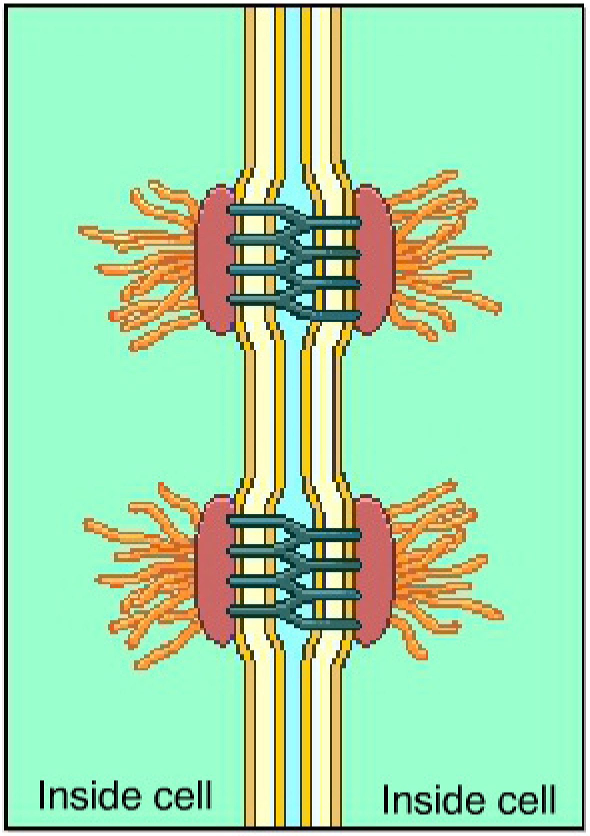
- Neighboring cells in an animal or plant often adhere, interact, and communicate through direct physical contact
- There are several types of intercellular junctions that facilitate this
  - Plasmodesmata
  - Tight junctions
  - Desmosomes
  - Gap junctions

Plasmodesmata in Plant Cells

- **Plasmodesmata** are channels that perforate plant cell walls
  - Unify most of a plant info one living continuum
- Through plasmodesmata, water and small solutes (and sometimes proteins and RNA) can pass from cell to cell

Tight Junctions, Desmosomes, and Gap Junctions in Animal Cells

- Animal cells have three main types of cell junctions
  - **Tight junctions**
    - Tight seals that prevent leakage
  - **Desmosomes**
    - Anchoring junctions
  - **Gap junctions**
    - Communicating junctions
- All are especially common in epithelial tissue, lining external and internal surfaces



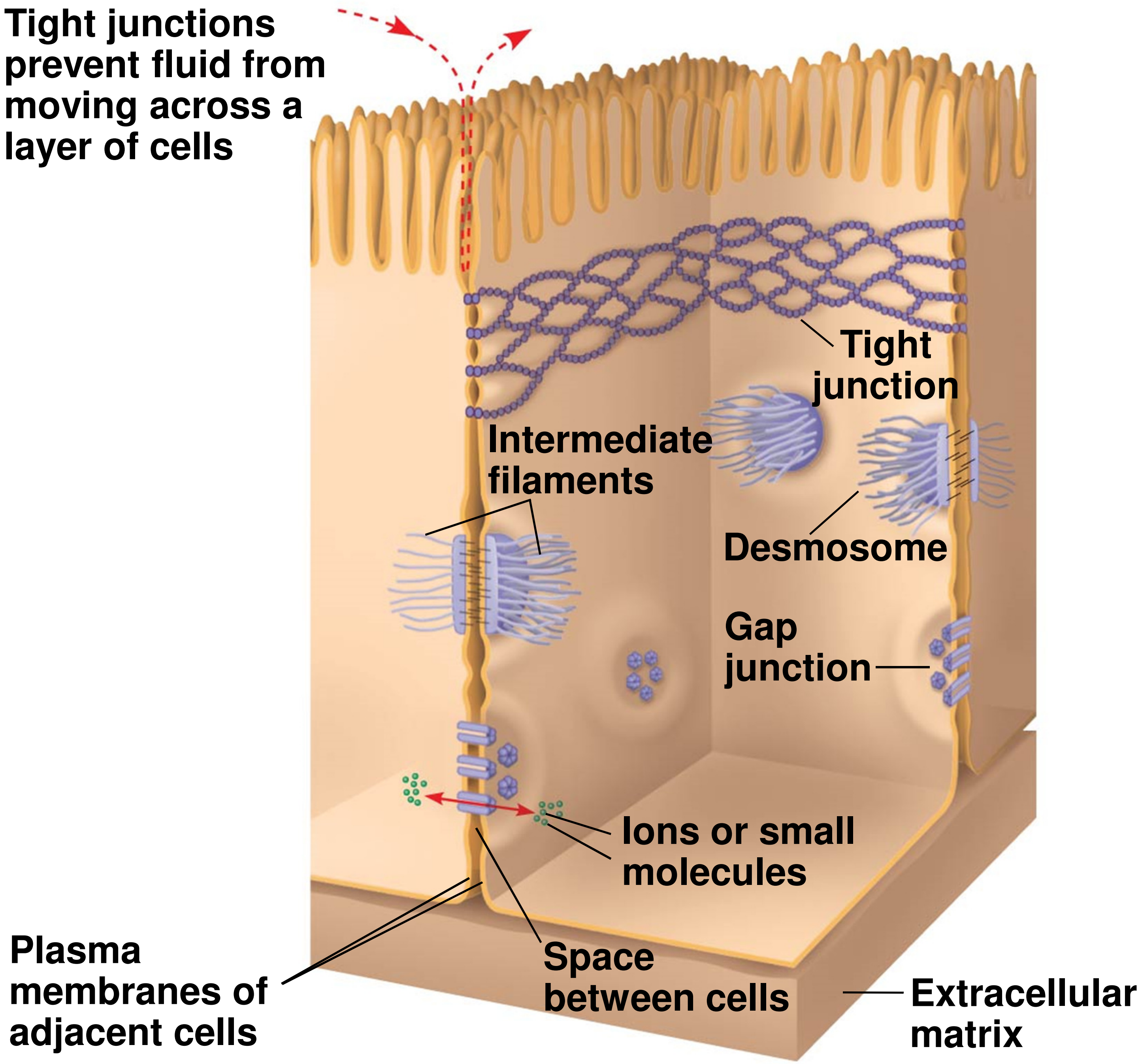
Animation: Desmosomes
Right click slide / Select play

Animation: Gap Junctions
Right click slide / Select play

Animation: Tight Junctions

Right click slide / Select play

Figure 4.27a


Tight junctions prevent fluid from moving across a layer of cells
Tight junction
Intermediate filaments
Desmosome
Gap junction
Ions or small molecules
Plasma membranes of adjacent cells
Space between cells
Extracellular matrix

The Cell: A Living Unit Greater Than the Sum of Its Parts

- Cellular functions arise from cellular order
- For example, a macrophage’s ability to destroy bacteria involves the whole cell, coordinating components such as the cytoskeleton, lysosomes, and plasma membrane